THE NATURE OF RADIOACTIVE FALL-OUT AND ITS EFFECTS ON MAN

U.S. Congress.

HEARINGS

BEFORE THE

SPECIAL SUBCOMMITTEE ON RADIATION

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY

CONGRESS OF THE UNITED STATES

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FIRST SESSION

ON

THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN

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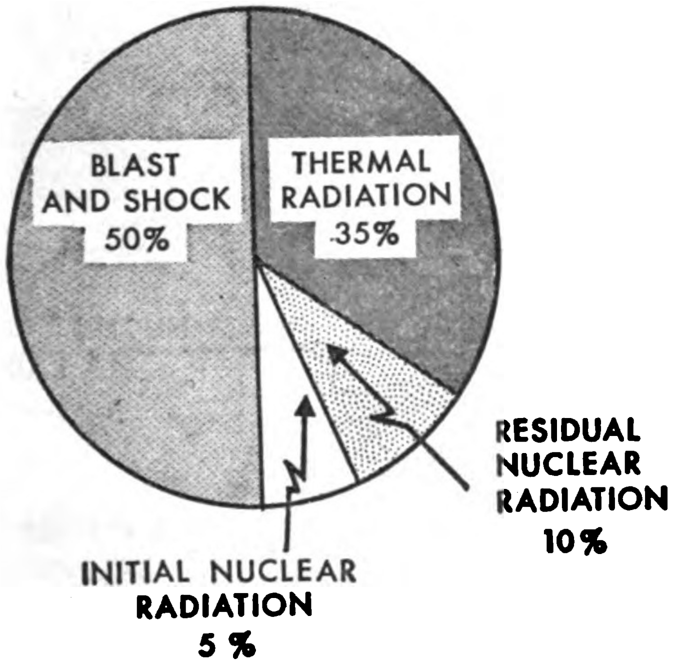

CHART II.—Distribution of energy in a typical air burst.

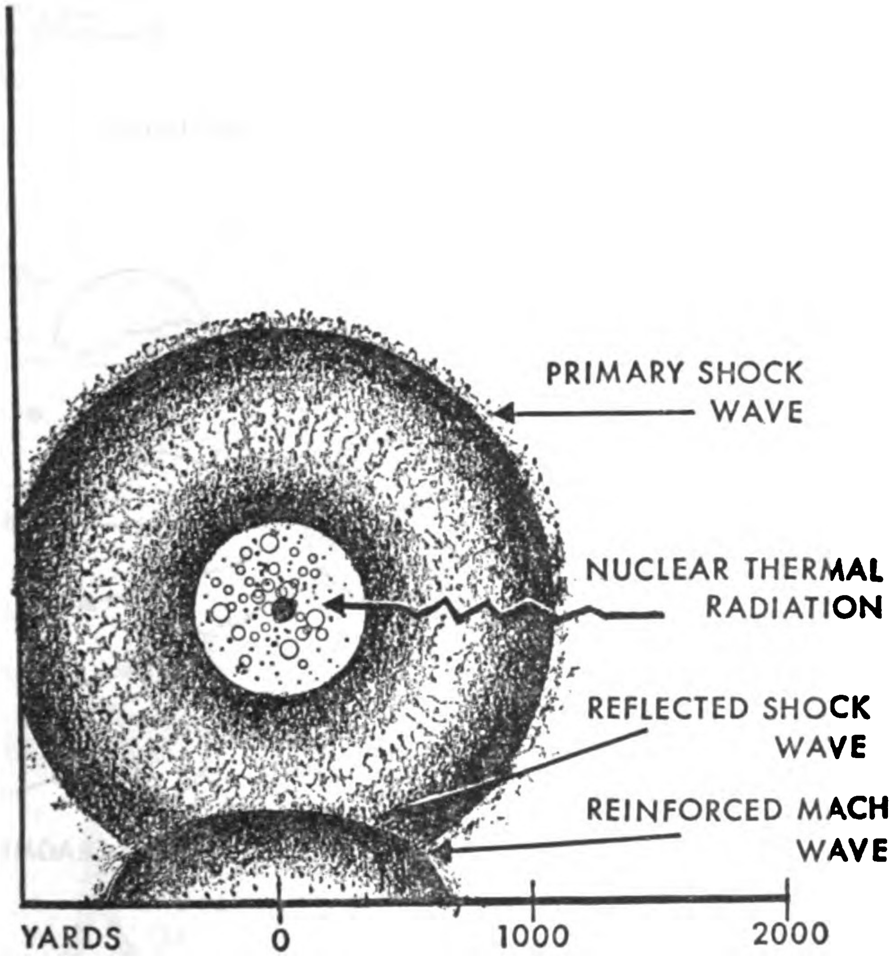

CHART III. Sectional view development of an atomic air burst.

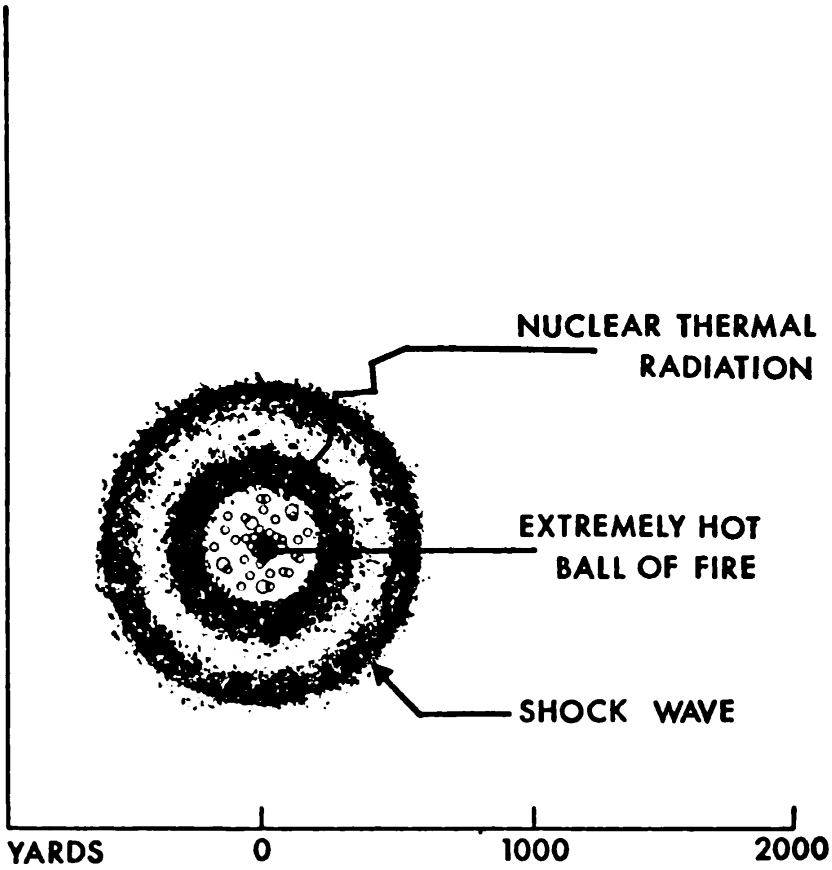

Chart IV

Sectional view development of an atomic burst.

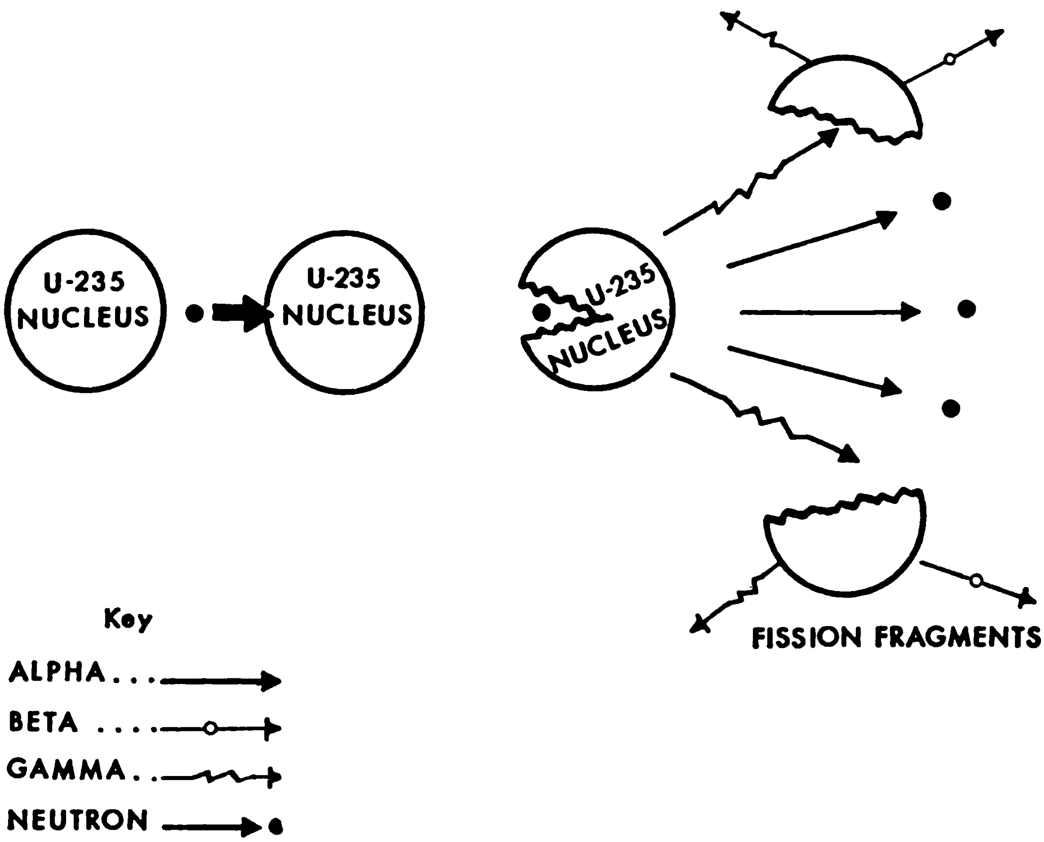

CHART V.—Fissioning of U-235 nucleus.

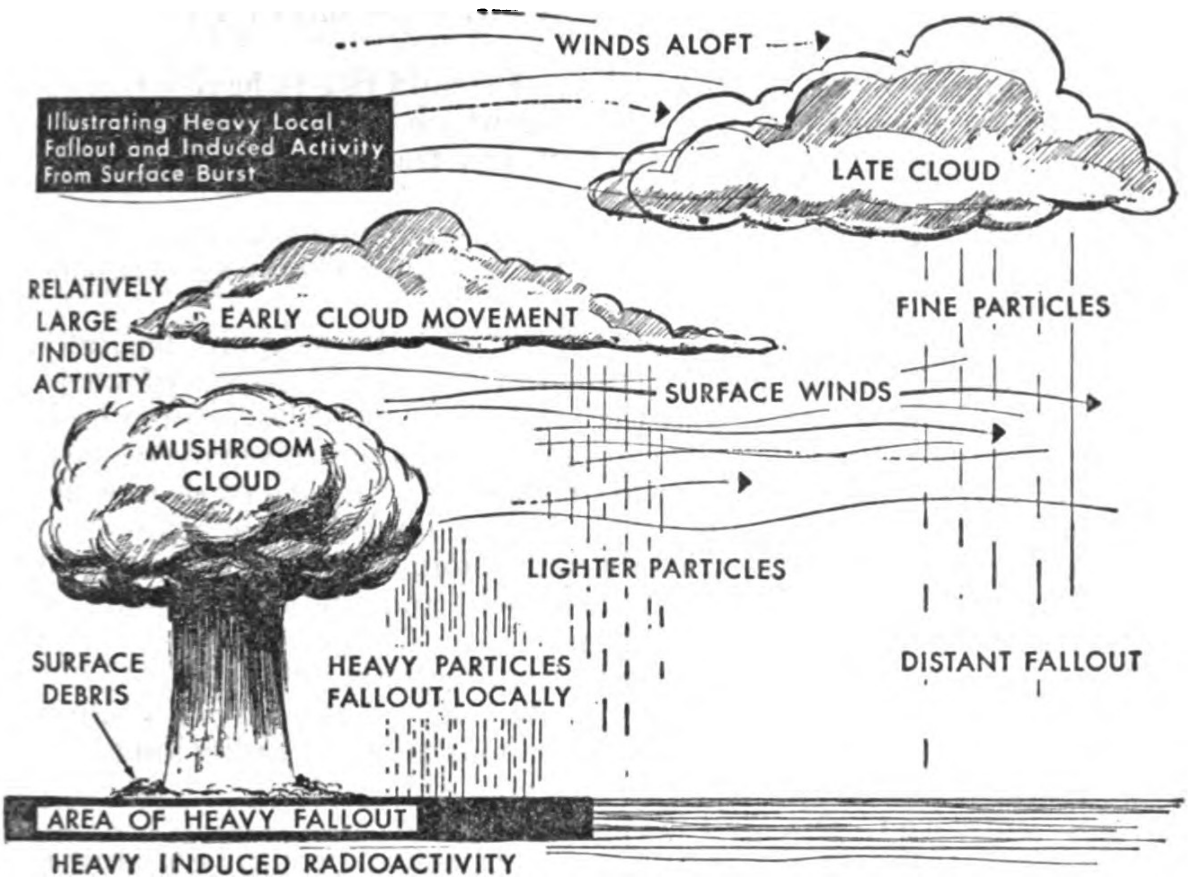

CHART VI.—SURFACE BURST

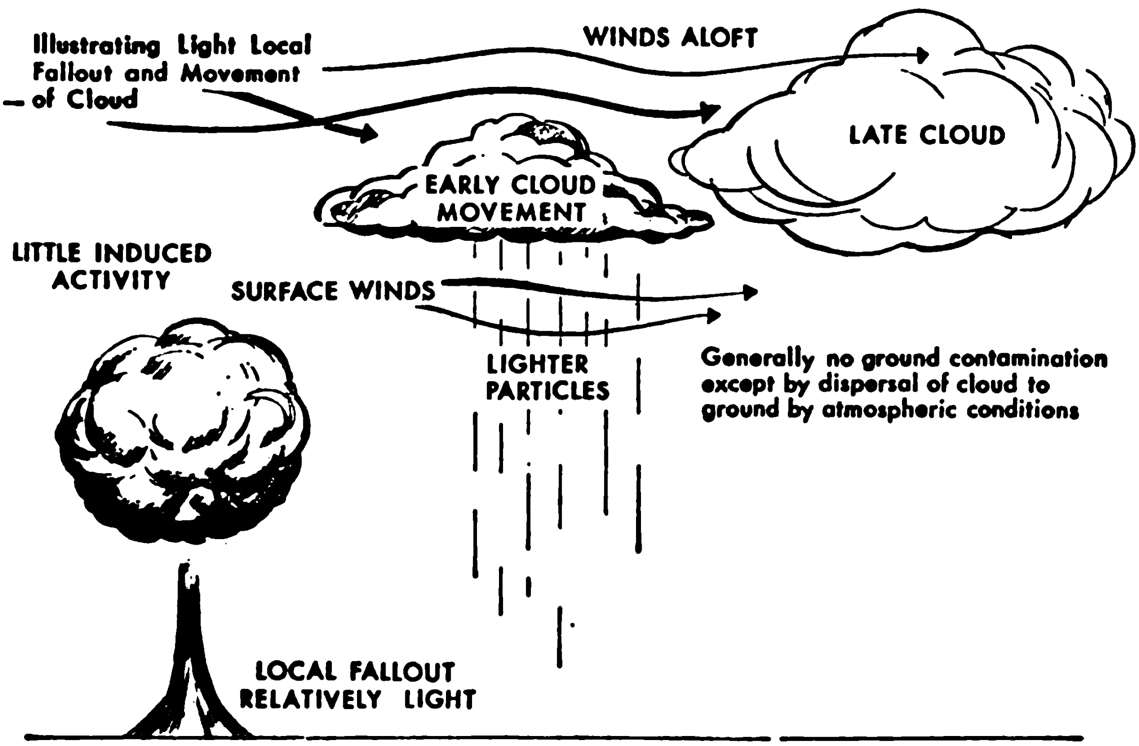

CHART VII.—AIRBURST

Representative VAN ZANDT. Mr. Chairman, may I ask this question. Doctor, how many roentgens did your body absorb in the Los Alamos accident?

Dr. GRAVES. I had about 200.

Representative COLE. From outward appearances you look rather healthy.

Dr. GRAVES. Thank you.

Representative COLE. At this time some several years later.

Dr. GRAVES. That was in 1946, so it has been 11 years. But this really is not important. You may have one person take 200 roentgens as I did and be perfectly happy for 10 years. But does it give me a greater probability of having cancer or does it give me a greater probability of this, that or the other, we just do not know. The danger is not that this will happen to you. The danger is that it is more likely to happen to you. Maybe the more likely is not very much more likely, but it is still more likely.

Representative VAN ZANDT. Doctor, how did this dose of radiation affect you?

Dr. GRAVES. I was nauseated for the first day. I was in the hospital for 2 weeks. I never did feel very sick but I was quite—I did not have very much ambition, I was tired, I got tired climbing steps and so on, and this lasted for perhaps 6 months. At the end of 6 months I was back to work, and I can't tell any difference now.

Representative VAN ZANDT. Did it affect your hair in any way?

Dr. GRAVES. I lost the hair on one side of my head. I did not have to shave for a while, which was a byproduct that was useful.

Representative VAN ZANDT. How about your eye?

Dr. GRAVES. I have a radiation cataract in one eye. The other eye is perfectly all right.

Representative HOLIFIELD. What was the white corpuscle count at the end of 6 months?

Dr. GRAVES. At the end of 6 months it was back to normal. You can't tell anything. You can examine me with a microscope or anything else, and you can't tell any difference now. At the time my white blood count dropped from about 8,000 or 9,000, which was normal, down to around 2,000. Again I don't have these numbers in front of me, so I don't remember exactly. But at the end of perhaps a week or 10 days the count began to increase again, and got back to normal. As a matter of fact, it got above normal. By 6 months it was back to normal, and stayed there ever since.

Representative HOLIFIELD. Dr. Graves, I think I express the feelings of every member of this committee that have known about this for so many years, that we are glad you are in as good health as you are today, and we want to again express our thanks to you for the tremendous contribution you have made to the security of our Nation.

Representative COLE. Mr. Chairman, I just want to concur in what you have said with respect to the attitude of the committee toward Dr. Graves' work. But since we have engaged in some rather personal questions of him with respect to consequences of his exposure, I would like to inquire if since that occurred you have increased your family in any way, and if so, whether the progeny is apparently normal and health. Mr. Chairman, I do not ask it facetiously. Here is a man

who has been exposed to a degree of radiation probably greater than any person that we know. He has told us the consequences to him of his own body. Since radiation exposure has been said to involve a question of sterility and so forth, unless he would rather not answer, I would like to give him the opportunity of indicating.

Dr. GRAVES. I had one daughter before the accident. I have had a daughter and son since the accident. The daughter and son as far as can be told are perfectly normal kids. We love them very much.

Representative VAN ZANDT. From a heredity standpoint, do they show any extraordinary amount of energy as a result of your brush with atomic energy?

Dr. GRAVES. Speaking as a parent they are very intelligent children.

Representative HOLIFIELD. Thank you very much. Our next witness is Dr. W. W. Kellogg of the Rand Corp. and he will speak to us on the subject of atmospheric transport, storage, and removal of particulate radioactivity.

Dr. Kellogg, how long is your presentation?

STATEMENT OF DR. W. W. KELLOGG, RAND CORP.[6]

Dr. KELLOGG. I have a report for the record which is somewhat long, and I was not planning to give it all now. It has a lot of documentation in it. I was going to abstract it to the committee orally. I could do it in 30 or 40 minutes. Is it too late to do that?

Representative HOLIFIELD. We will accept your prepared statement for the record. We will be glad to have you summarize it.

(The statement referred to follows:)

ATMOSPHERIC TRANSPORT AND CLOSE-IN FALLOUT OF RADIOACTIVE DEBRIS FROM ATOMIC EXPLOSIONS

(By Dr. William W. Kellogg, RAND Corporation)

INTRODUCTION

It is well known that the radioactive debris from an atomic explosion is carried high into the atmosphere, and that eventually all of it reaches the ground. However, there are a variety of things which can happen to these particles on their way to ground, and their paths can be quite complicated. The purpose of the present report is to describe and document part of this process of radioactive fallout.

In order to limit the discussion, fallout here will be taken to mean "close-in fallout," the fallout which occurs during the first day or two following the explosion, and which deposits radioactivity within a few hundred miles of ground

[6] Born: February 14, 1917, at New York Mills, N. Y. Educated: Brooks School, North Andover, Mass.; Yale University, bachelor of arts, 1939; University of California, Berkeley, graduate studies in physics; UCLA, master of arts in meteorology, 1942; UCLA, doctor of philosophy in meteorology, 1949. Occupations: Prep school science teacher (Brooks), 1939–40; teaching assistant, physics, University of California, 1940–41; U. S. Air Force, pilot weather officer, separated with rank of captain, 1941–46; research assistant, research associate, and assistant professor (in succession), Institute of Geophysics, UCLA, 1946–52; research scientist, the Rand Corp., Santa Monica, 1947–present. Affiliations: American Meteorological Society (committee on admissions upper atomsphere committee); American Geophysical Union (upper atmosphere committee); Society of Sigma Xi; member, meteorological committee on the biological effects of atomic radiation, National Academy of Sciences-National Research Council; member, working group in internal instrumentation of the earth satelite program; member, ad hoc panel for measuring radioactivity in air of the United States National Committee for the International Geophysical Year; formerly member, upper atmosphere committee, NACA (now defunct). (Submitted by Witness.)

zero. The intermediate scale of fallout (that which occurs in the first few weeks) and the worldwide fallout will be treated by others.

Although the purpose is to tell what we know about fallout, an effort will also be made to point out the areas of uncertainty in our knowledge. Fallout is a process which is affected by many different things, and the atmosphere by its very nature behaves in an erratic and random way. Thus, it is fair to say at the outset that, no matter how well we could document our observations of fallout, there would still be an area of uncertainty due to the randomness of the process. This aspect should be borne in mind in considering the evidence which follows.

DESCRIPTION OF THE PROCESS OF CLOSE-IN FALLOUT

There is a fundamental difference between the fallout from an atomic device detonated at the ground and the fallout from one detonated so high that the fireball does not touch the ground. In the case of the surface burst, large quantities of surface material are broken up, melted, and even vaporized, and some of this material comes in intimate contact with the radioactive fission products. Then, after the atomic cloud has stopped rising and the violent updrafts associated with the explosion have subsided, the larger and heavier particles start falling back to the ground. The result is an area around ground zero and extending downwind which is covered in a more or less systematic way with particles contaminated by atomic debris.

In the case of an air burst in which the white-hot fireball never reaches the surface, the radioactive fission products never come into close contact with the surface material; they remain as an exceedingly fine aerosol. At first sight this might be thought to be an oversimplification, since there have been many cases in which the fireball never touched the ground, but the surface material was observed to have been sucked up into the rising atomic cloud. Actually, however, in such cases a survey of the area has shown that there has been a negligible amount of radioactive fallout on the ground. Though tons of sand and dust may have been raised by the explosion, they apparently did not become contaminated by fission products.

The explanation for this curious fact prabably lies in a detailed consideration of the way in which the surface material is sucked up into the fireball of an air burst. Within a few seconds from burst time, the circulation in the atomic fireball develops a toroidal form, with an updraft in the middle and downdraft around the outside. Most of the fission products are then confined to a doughnut-shaped region, and may be thought of as constituting a smoke ring. When the surface debris is carried into the fireball a few seconds after the detonation, it passes up along the axis of the cloud, through the middle, and can often be seen to cascade back down around the outside of the cloud. In its passage through the cloud, it has passed around the radioactive smoke ring but has never mixed with it.[1]

There has not been a large number of surface shots in the United States test series, and most of these have been set off in the Pacific area, where complete documentation of the fallout has been difficult because the greater part of the material came down in the open ocean or in the water of the lagoons. During the last Pacific test, however, a method of surveying the ocean to determine the distribution of the fallout was used which has given us some fairly complete and quantitative data on the pattern of the fallout from some larger yield devices.[2] A reanalysis of the fraction of the debris which came down within the first few hundred miles from the various Operation Redwing surface shots by Tucker,[3] based on the ocean and atoll survey made jointly by the Scripps Institute of Oceanography, the Naval Radiological Defense Laboratory, the Evans Signal Laboratory, the New York Operations Office of the AEC, the Chemical Warfare Laboratories of the Army Chemical Center, and the Air Forces Special Weapons Center, reveals that from a large yield surface burst about 85 percent falls down in roughly the first 24 hours; for a barge shot in the water of a lagoon the fraction is between 65 and 70 percent. According to Tucker, the accuracy of the estimates

[1] Kellogg, W. W., R. R. Rapp, and S. M. Greenfield: Close-In Fallout, Jour. Met., vol. 14, No. 1, pp. 1–8, 1957.

[2] Van Lint, V. A. J., L. E. Killion, J. A. Chiment, and D. C. Campbell: Fallout Studies During Operation Redwing, Field Command, AFSWP, Operation Redwing Preliminary Report, ITR–1354, October 1956 (Secret, R. D.).

[3] Tucker, B. L.: Fraction of Redwing Radioactivity in Local Fallout, RAND Corp., Report in preparation, May 1957 (Secret, R. D.).

here is probably no better than 20 or 30 percent, so the good agreement which he obtained for various kinds of shots may be fortuitous.[4]

The one other piece of evidence on the fraction falling out from a surface shot comes from Operation Jangle. The Los Alamos Health and Safety Division had a number of stations downwind to record the fallout, and the Air Force surveyed a larger area by flying an instrumented aircraft at low altitudes over the desert. Two analyses have been made of the resulting fallout pattern in order to estimate the fraction of the debris which was represented, one by Lulejian[5] and the other by Rapp.[6] The results are as follows:

	Percent
Lulejian: Beyond 10 miles from ground zero and within 200 miles	60±20
Rapp: Beyond 4 miles from ground zero and within 200 miles	77
Rapp: Total fallout out to 200 miles	87

It should be noted that the famous March 1, 1954, test of the Castle series in the Pacific, which received some publicity because of the fallout on some nearby inhabited atolls,[7] was not well enough documented to enable one to get a good estimate of the percentage of fallout. In order for such an estimate to be made it is clearly necessary to be able to lay out the *complete* fallout pattern. This was not possible here, since the islands on which the fallout occurred occupied only a part of the pattern, and were probably not in the region of maximum fallout. This event will be discussed more below.

As pointed out above, if the height of burst is raised, the amount of surface material which can become intimately mixed with the fission products becomes less. As a result, the fraction which takes part in close-in fallout decreases with increasing height of burst. A tower shot does not exactly follow this trend, however, since the material in the tower itself and in the cab at the top of the tower apparently provides some radioactive fallout. The fraction falling out from a tower shot appears to be quite variable, as can be seen from the following tabulation prepared by Kenneth Nagler and Dr. Lester Machta of the United States Weather Bureau, based on a detailed analysis of the actual fallout from a number of tests in Nevada, all of which had yields in the range of 12 to 18 kt.

	Percent
800-foot tower	17.8
	12.3
	8.9
	7.8
	7.0
Average	10.8
500-foot tower	5.4
524-foot airburst (especially uncertain)	1.0

It should be noted that the particular airburst cited here produced a fireball which almost touched the ground. Higher airbursts, as mentioned above, produce no significant close-in fallout.

So far the discussion has been concerned with the *total amount* of radioactive material taking part in the fallout. The *distribution* of this material on the ground depends on a number of parameters—wind structure, yield and height of burst, and kind of surface. The yield and height of burst predominantly determine the distribution of radioactivity with size of particle, and the height and size of the cloud at time of stabilization. The kind of soil taken into the fireball presumably has an effect on the particle size distribution too. In order to make a calculation of where the debris will go, all these factors must be taken into account in one way or another. The various ways of handling this complicated situation are treated in the next section.

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[4] In ref. 2, Appendix E, similar estimates are made which are less than the ones quoted. However, it appears that a different "normalization factor" was used to convert from kt yield to megacurries of fission product activity at one hour, and this was combined with an inappropriate decay rate to convert from the time of observation to the reference time of 1 hour. Further, Tucked introduced a correction for the radioactive sodium from the ocean water which was activated by neutrons from the explosion, and which contributed to the observed radioactivity.

[5] Lulejian, N. M.: Radioactive Fallout from Atomic Bombs, Air Research and Development Command, C3-36417 (with supplement), November 1953 (Secret, R. D.).

[6] Greenfield, S. M., W. W. Kellogg, F. J. Krieger, and R. R. Rapp: Transport and Early Deposition of Radioactive Debris from Atomic Explosions, Report of Project Aureole, Rand Corp., R-265-AEC, July 1954 (Secret, R. D.). See chapter 4.

[7] Cronkite, E. P., V. P. Bond, and C. L. Dunham: Some Effects of Ionizing Radiation on Human Beings, United States Atomic Energy Commission, July 1956.

Before proceeding further it might be well to mention something about what happens to these radioactive particles after they are on the ground. The largest particles involved may be a millimeter or more in diameter, but these constitute only a small fraction of the total debris. Both observation of the particles, collected in many ways in the Pacific and in Nevada, and theoretical calculations of the way in which they must fall indicated that the majority of the particles taking part in the close-in fallout have diameters between about 50 and 400 microns (1 micron is 10,000 cm.).[8 9 10 11] According to G. R. Hilst, of the Hanford Atomic Products Operation, particles of less and about 50 microns diameter are difficult to erode by wind action because they tend to sift down and cling between the larger particles of the soil, and particles larger than about 500 microns diameter are difficult to erode because the wind cannot easily lift them. The particle size range in which radioactive fallout lies is the size which can be most easily lifted by the wind and redeposited somewhere else. Under high wind conditions this could further complicate the prediction of where the debris would go.

COMPUTING FALLOUT PATTERNS

Clearly, the direction that a particle takes on its way to the ground is determined by the wind. It is not the wind at one level alone which must be considered, but the cumulative effect of all the winds between the ground and the initial altitude of the particle. There have been a number of mehods developed to make some sort of best guess about where the debris will be deposited, and these all have one element in common: The wind field from the ground up to the atomic cloud must be analyzed and integrated.

In order to understand the matter of fallout computation, it is necessary to see what is involved in an integration of the wind field. Figure 1 shows, in schematic form, how such an integration can be done vectorially. Let it be assumed for the moment that a particle starting from 50,000 feet, for example, has a constant rate of fall. In such a case it will spend the same amount of time in each layer of a given thickness, say 5,000 feet. The direction of its travel while in a given layer will be in the direction of the mean wind in that layer, and the distance it travels while in the layer will be proportional to the length of the corresponding wind vector. Then it falls down into the next layer and again travels with the mean wind in that layer. In order to determine the total distance and direction which this particle traveled on the way to the ground it is only necessary to add the successive wind vectors for each layer head to tail, and the resultant vector will represent the total travel.

In practice, meteorologists have found it convenient to add the vectors starting from the ground and working upward, as shown in figure 1b. Now the integrated wind, or total particle travel, from any given altitude can be immediately determined by drawing a vector from the origin to the head of the arrow corresponding to the correct altitude. In other words, a family of integrated winds can be produced in this way, and the direction and rate of travel of all particles can be estimated by inspection of the diagram. Recall that it was assumed here that the particles fell at a constant rate. This is not the case in actuality, and so the simple vector addition described here must be modified in the more sophisticated analyses of fallout.

There have been four main approaches to the construction of a fallout analysis, depending on the amount of time available for the computation and the degree of completeness required. It should be emphasized that these various approaches do not compete with each other, since they are each tailored to answer a different set of questions about the fallout, and they differ greatly in the amount of labor required to carry them out. In order of increasing complexity, they are—

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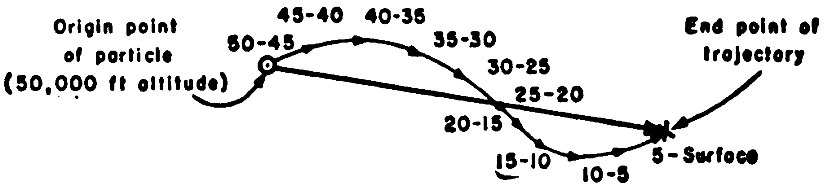
[8] Rainey, C. T., J. W. Neel, H. M. Mork, and Kermit H. Larson: Distribution and Characteristics of Fall-Out at Distances Greater than 10 Miles from Ground Zero, March and April 1953, U. C. L. A. School of Medicine, Operation Upshot-Knothole, WT-811, February 1954 (Secret, R. D.).

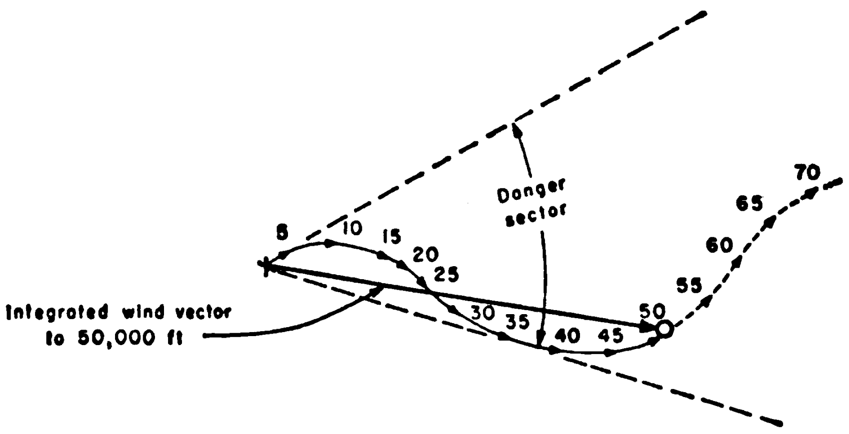
[9] Heidt, W. B., Jr., E. A. Schuert, W. W. Perkins, and R. L. Stetson: Nature, Intensity, and Distribution of Fallout from Mike Shot, U. S. Naval Radiological Defense Lab., Operation Ivy, WT-615, November 1952 (Secret, R. D.).

[10] Stetson, R. L., E. A. Schuert, W. W. Perkins, T. H. Shirasawa, and H. K. Chan: Distribution and Intensity of Fallout, U. S. Naval Radiological Defense Lab., Opertaion Castle, WT-915, January 1956 (Secret, R. D.).

[11] Wilsey, E. F., R. J. French, and H. I. West, Jr.: Fallout Studies, Army Chemical Center, Operation Castle, WT-916, February 1956 (Secret, R. D.).



(a) Actual particle trajectory



(b) Usual method of plotting and
integrating the wind field

FIGURE 1.—Schematic representation of a wind field and the analysis of a falling particle's trajectory.

1. *The danger sector.*—An inspection of the integrated wind plot shown in figure 1b shows that all the particles starting in a vertical line over the origin would travel within the sector indicated by the dashed lines. This can be called the danger sector, since it is the sector within which the debris will fall, more or less, assuming a perfectly constant wind field. Certain refinements can be made to the simple sector presentation with little effort, such as delineation of the times at which the particles starting over ground zero will reach a given point on the ground; and the finite initial size of the atomic cloud can be taken into account graphically. This approach has been described in detail in several readily available reports.[12, 13, 14] Since it is quick and convenient, it is the method which has been recommended by the Weather Bureau, the Air Weather Service, and the FCDA for use in weather stations in an emergency. In order to further expedite the computation, the Weather Bureau has recently instituted the inclusion of the integrated winds from each upper wind station in the routine teletype message. These go by the code name of "UF winds," and are available from about 70 weather stations within the United States twice daily. Note, however, that the danger sector method does not provide a way for telling the actual levels of activity and does not distinguish the parts of the sector which are more intensely contaminated, though there are some methods for roughly estimating where these will be.

2. *The idealized pattern.*—Several of the earlier workers in the field of fallout noted the fact that the majority of the patterns (in Nevada) had a characteristic cigar shape.[5, 15] It was therefore tempting to attempt to characterize fallout patterns in general in terms of a family of simple elliptical shapes, with a circular

[12] Air Weather Service Manual 105–33, Radioactivity Fall-Out and Radex Plots, Hqs., Air Weather Service, June 2, 1952.

[13] Construction of Fallout Plots from Coded Messages Provided by the U. S. Weather Bureau," Federal Civil Defense Administration, Battle Creek, Advisory Bulletin No. 188, May 25, 1955 (and supplements).

[14] Training Manual for Computing and Coding Civil Defense Fallout Winds, U. S. Weather Bureau, Washington, April 1955.

[15] Laurino, R. K., and I. G. Poppoff: Contamination Patterns at Operation Jangle, U. S. Naval Radiological Defense Laboratory, Rept. 399, April 1953 (Secret, R. D.).

section around ground zero. The Armed Forces special weapons project (AFSWP) and others have, over a period of years, developed rather elaborate sets of scaling and shaping laws, designed to fit these idealized patterns to a wide range of yields and, to a limited extent, wind conditions. These methods are described in detail elsewhere.[16] A recent report of the Air Force Special Weapons Center by Boyd and Baker has summarized and made comparisons of the various methods.[17] They all have the common characteristic that the only input required is the weapon yield (a surface burst is assumed) and some sort of an integrated wind, sometimes called the effective wind. For certain planning purposes these idealized fallout patterns are quite useful, since they give a good idea of the area covered by a given dose contour, and for a simple wind structure the orientation and shape may be quite representative. However, as our experience with actual fallout patterns grows, it becomes clear that the simple wind structure required to lay down a symmetrical pattern like the idealized ones is not necessarily the expected one, particularly in the Tropics or in Nevada in summer. Therefore, for prediction purposes such a method may be of little value; moreover, the way in which it is presented gives an erroneous impression of the accuracy of the plot, since the dose rate contours are actually specified.

3. *Analog method.*—A very common technique in weather forecasting, one which all meteorologists use either subconsciously or consciously, is the use of analogs. Essentially, this means a sorting over of cases which have occurred in the past to find a situation analogous to the current situation, and presuming that the same processes will follow the same course again. There have not been enough surface bursts to build up a good file of analogs, but an artificial set can be calculated, using the sort of detailed calculations to be described in the next section. Such a "catalog" of fallout patterns has already been produced by the Rand Corp.[18] To make use of this collection of analogs, the meteorologist must find a wind field in the catalog which by proper manipulation can be more or less matched to the current wind field, and he can then take advantage of the fact that the resulting fallout pattern has already been computed in great detail. If the yield does not match, then certain scaling laws can be applied to the analog to make it the correct size. Naturally, the same wind field never occurs exactly the same way twice, but the matching can be done quite successfully over a wide range of conditions and yields.

4. *Fallout models.*—In attempts to describe as closely as possible what actually happens in the fallout process, several agencies have developed techniques in which the particles in the initial atomic cloud are traced down to the ground, and in which their combined effect is then calculated for each point in the fallout field. The result is a polt of the expected dose rate at any given point for a given time. In order to perform such an elaborate computation the following factors must all be considered:

Wind field—in some of the computations it is not only possible to consider the variation with height, but the variation with time and space. Under certain conditions, as will be shown, such variations are quite important.

Initial distribution of particles in space—although the size and shape of the atomic cloud can be observed photographically, the distribution of the radioactivity inside the cloud is not well known. Assumptions about this vary from model to model.

Size distribution of the particles—since the larger particles will in general fall faster than the smaller ones, it is necessary to specify how much of the total radioactivity is associated with each range of particle size. Furthermore, the size distribution probably differs in different parts of the cloud, a feature which some of the models attempt to take into account.

Rate of fall—the rate of fall of a particle depends on its size, density, and shape. Thus, the rates of fall of a given size particle at each altitude must be specified in each model.

Turbulent diffusion—in at least one of the models which has been tried the spread of the trajectories due to random turbulence has been taken into

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[16] Capabilities of Atomic Weapons, Armed Forces Special Weapons Project, TM 23-200/OPNAV Instruction 003400. IA/AFL 136-4/NAVMC 1104, Washington, 1955 (Secret, R. D.). (See sec. 13.)

[17] Boyd, R. E., and D. Baker: Comparison of Methods Used in Scaling Residual Contamination Pattern Resulting from Surface Detonations of Nuclear Weapons. Hqs., Air Force Special Weapons Center. Kirtland AFB. AFSWC-TN-56-1, April 1956 (Secret, R. D.).

[18] S. M. Greenfield, R. R. Rapp, and P. A. Walters: A Catalog of Fallout Patterns, Rand Corp., Rept. RM-1676, April 1956.

account. However, most of the models choose to neglect this effect, since it does not appear to be very important for the early deposition.

Each of the computational models must specify all of the above factors, and there have been some rather large differences between the assumptions, due to our lack of very definite information about the true facts of the matter. In addition, different computational techniques are used to analze the model, some using high speed digital computers, some using special electronic or optical analog computers, and some using a graphical "hand" computation.

In January 1955, the Armed Forces Special Weapons Project (AFSWP) organized a symposium on radioactive fallout, and all the various agencies which had studies the question of fallout were invited to apply their respective fallout models to two specified sets of wind conditions, known as condition A and condition B. The results, as published in the AFSWP report on the symposium [19] are shown in figures 2 and 3. The winds used are tabulated in table 1 and table 2. For details of the actual computational schemes used, one should refer to the fallout symposium report [19] or to the reports of the various agencies, some of which have become unclassified.

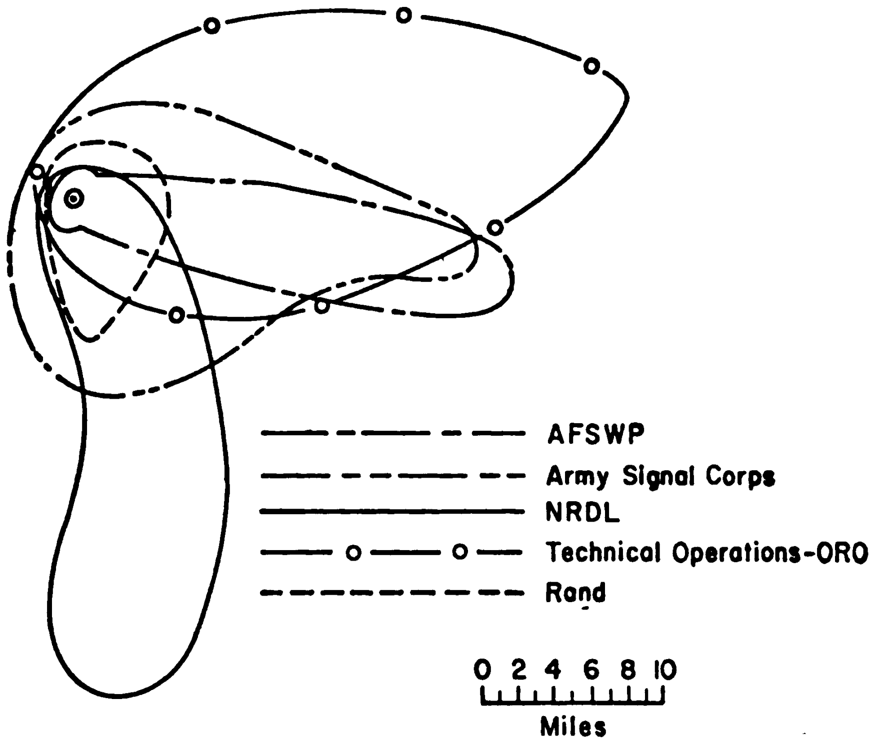

FIGURE 2.—AFSWP comparison of fallout computations (Ref. 18). Cases for "Condition A," 1 megaton yield, showing contours for 1,500 r dose accumulated by 48 hours.

TABLE 1.—*Condition A—Wintertime situation of an abrupt, approximately 90°, shear at a height of approximately 40,000 feet*

[Dodge City, Kans.—37°46′ N. 99°58′ W.—1500 Greenwich meantime—Dec. 28, 1953—Elevation: 2,625 feet]

Height (feet, mean sea level)	Wind direction (degrees)	Wind speed (knots)	Height (feet, mean sea level)	Wind direction (degrees)	Wind speed (knots)
Surface	260	7	45,000	255	43
5,000	247	12	50,000	255	55
10,000	273	19	55,000	260	47
15,000	307	13	60,000	272	54
20,000	008	16	65,000	289	40
25,000	045	41	70,000	285	36
30,000	036	52	75,000	285	38
35,000	357	29	80,000	285	45
40,000	243	47			

[19] Fallout Symposium, Armed Forces Special Weapons Project Report 895, January 1955 (secret, R. D.).

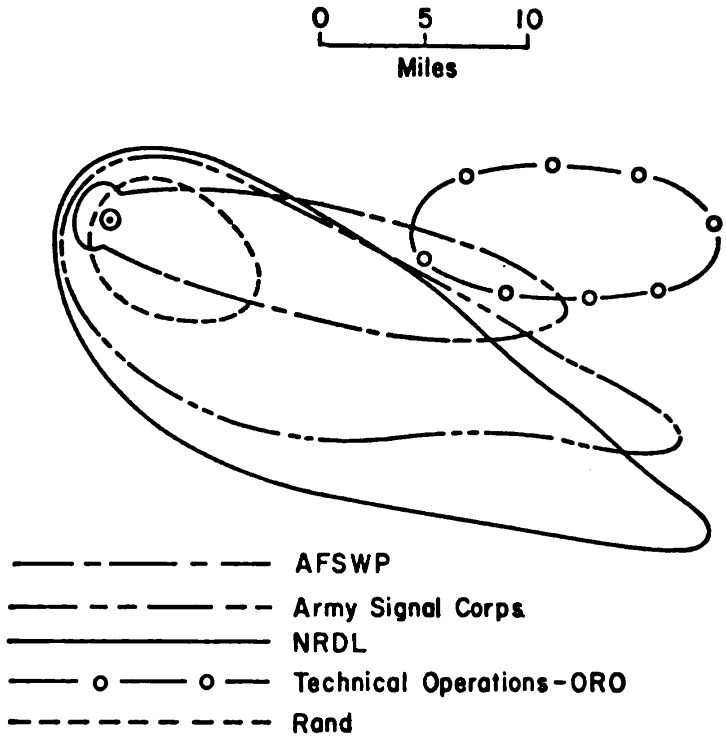

FIGURE 3.—AFSWP comparison of fallout computations (Ref. 18) cases for "Condition B," 1 megaton yield, showing contours for 1,500 r dose accumulated by 48 hours.

TABLE 2.—*Condition B—Gradual shear of approximately 90°*

[Washington, D. C. (Siver Hill)—38°50′ N., 76°57′W.—0300 Grenwich mean time—Sept. 28, 1952—Elevation: 289 feet]

Height (feet, mean sea level)	Wind direction (degrees)	Wind speed (knots)	Height (feet, mean sea level)	Wind direction (degrees)	Wind speed (knots)
Surface	Calm	0	45,000	292	23
5,000	358	11	50,000	290	28
10,000	009	20	55,000	290	20
15,000	325	14	60,000	268	11
20,000	282	19	65,000	276	21
25,000	263	34	70,000	293	7
30,000	263	47	75,000	293	8
35,000	273	37	80,000	285	10
40,000	308	27	85,000	250	11

The significant thing to note is the discouragingly poor agreement between the various results. It is possible that some of the agencies have modified their models in the past 2 years, and that there would be better agreement if the exercise were repeated now, but it is highly unlikely that the agreement would be anywhere nearly exact. It would seem that we simply do not know enough yet about the process of fallout to be able to reconstruct a fallout model (no matter how sophisticated in conception) on which everyone would agree.

PREDICTION AND RECONSTRUCTION OF FALLOUT PATTERNS

As stated in the previous section, there have been a number of methods develeped for the computation of fallout patterns. Naturally, these were developed with the observed fallout from a handful of surface and tower bursts in hand, and all claim (to a greater or lesser degree) to give results which agree with reality.

The real question of agreement with reality is, however, obscured by the fact that reality is hard to define, even in retrospect, when all the facts are collected. First, the wind field is poorly observed, and the variations in the wind field with time and space are difficult to take into account in reconstructing what

happened. The meteorological literature has a number of studies of this variability and of the uncertainties in observation,[20 21 22] A good rule of thumb, derived from experience with the tracking of constant-level balloons, is that, over a good upper air network of the sort which covers the United States, the path of a particle cannot be determined from an analysis of the wind field to better than 20 percent of the length of the trajectory. Thus, after going 100 miles, the uncertainty in the position of a drifting particle is about 20 miles, even when we have all the upper-air data which we can lay our hands on.

Furthermore, the fallout itself is poorly observed, due to the great distances that have to be covered, the irregularities of the terrain (in Nevada) or the uncertainty of where it went after landing in the ocean (in the Pacific). Thus, even if our computation were, in principle, a perfect one, we would still not have a clear picture against which to compare it.

When the meteorologist is faced with the problem of *predicting* a fallout pattern, the uncertainties of a wind prediction are added to the uncertainties in the computational model. The longer the time lag between prediction and the event, the greater will be the uncertainties.[23] For times of up to 12 hours, it appears that persistence is about as good as a forecast, and after about 2 to 3 days a forecast is not much better than a climatological mean.

Without belaboring this point, it should suffice to show two interesting examples of predicted and reconstructed fallout patterns. One is from a burst of roughly 30 kilotons on a tower in Nevada, the Open or Civil Defense shot of May 5, 1955. The patterns shown in figures 4 and 5 were prepared by Kenneth Nagler, of the United States Weather Bureau, and show the patterns which were predicted 2 hours before shot time by 2 methods of models. The two models, one of the Weather Bureau and the other of the Los Alamos Scientific Laboratory and the University of California Radiation Laboratory, were used. The first involved a hand computation by an elaborate graphical analysis, the other involved a high speed digital computer (IBM–701). There were some differences in the two models, but these were not basic ones—that is, they both used the general approach described in the previous section. It will be noted that both methods predicted patterns extending due north from the shot point, following the direction of the H–2 hour predicted wind. The observed pattern, shown in figure 6, was reconstructed from the available road monitoring and from a few aircraft measurements by Nagler. The fallout started out northward, and then curved to the eastward, reflecting a gradual shift in the wind direction from south to west that took place in the hours following the shot. Also shown in figure 6 is an attempt to reconstruct the pattern, using the Weather Bureau's model and taking into account the change of wind with time and space. The result agrees with the obesrved pattern better, but still not perfectly.

Another example of a fallout pattern which changed its direction during the later stages of the fallout is the March 1, 1954, Castle shot on the Bikini atoll, referred to earlier. In this case, the fallout apparently started out in a direction east-northeast, but a continued veering of the wind caused it to curve more to the east and east-southeast, until one side of it lay across some neighboring atolls. A study of this event by Rand in which the fallout was computed with the shot-time wind alone, and then again with the variable (true) wind, shows clearly how the pattern must have curved as it progressed.[24]

It is interesting to note that both of these examples demonstrate the effect of the changing wind with time, an effect which is often very hard for the meterologist to specify. A study of the statistics of this change of wind with time has been made by Frank Cuff, department of meteorology, University of Utah.[25] Referring to the integrated wind (see above) from the ground up to various altitudes in Nevada, he found the mean absolute bearing changes shown in table 3.

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[20] Neiburger, N., L. Sherman, W. W. Kellogg, and A. F. Gustafson: On the Computation of Wind from Pressure Data, Jour. Met., vol. 5, No. 3, pp. 87–92, 1948.

[21] Rapp, R. R.: The Effect of Variability and Instrumental Error on Measurements in the Free Atmosphere, New York University Meteorological Papers, vol. 2, No. 1, June 1952.

[22] Kochanski, A. B.: Wind, Temperature, and Their Variabilities to 120,000 Feet, Air Weather Service Technical Report, 105–142, May 1956.

[23] Ellsaesser, H. W.: Errors in Upper-Level Wind Forecasts, Air Weather Service Technical Report, 105–140/1, December 1956.

[24] Greenfield, S. M., and R. R. Rapp: Fallout Computations and Castle-Bravo—A Case Study, Rand Corp., RM–1855, January 1957 (secret, R. D.).

[25] Cuff, R. D.: A Study of the Time Variability of Integrated Winds Near Las Vegas, Nevada, thesis for M. S. Degree, Dept. of Meteorology, Univ. of Utah, March 1957.

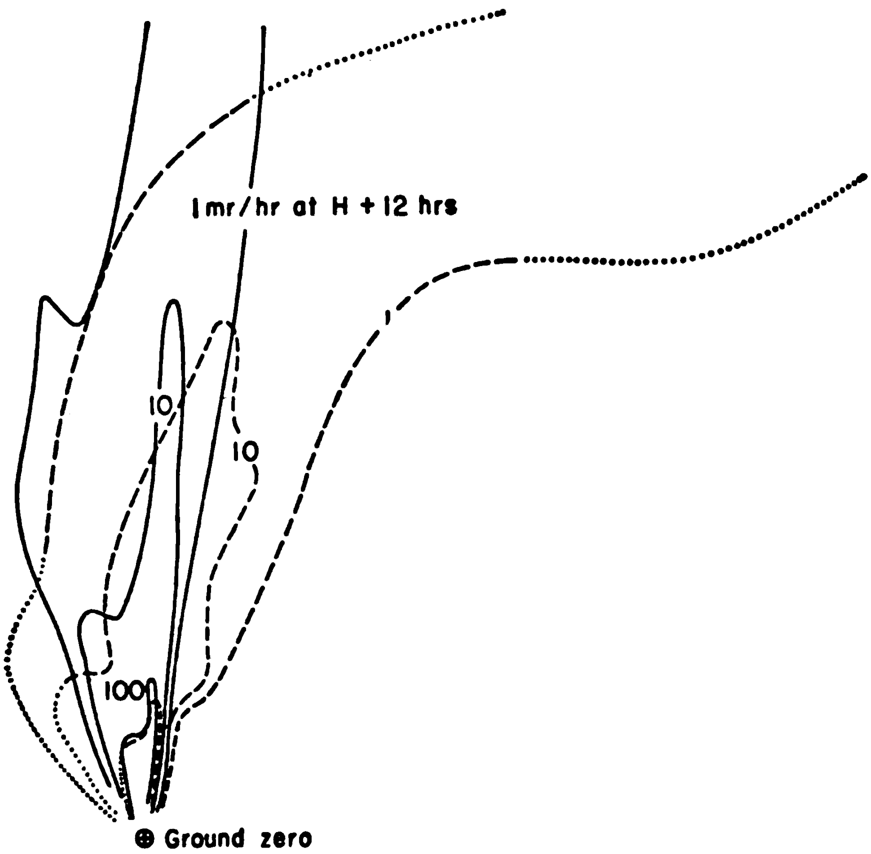

FIGURE 4.—The observed fallout distribution (dashed lines) and the pattern computed by the Weather Bureau using winds predicted at H-2 hours. May 5, 1955.

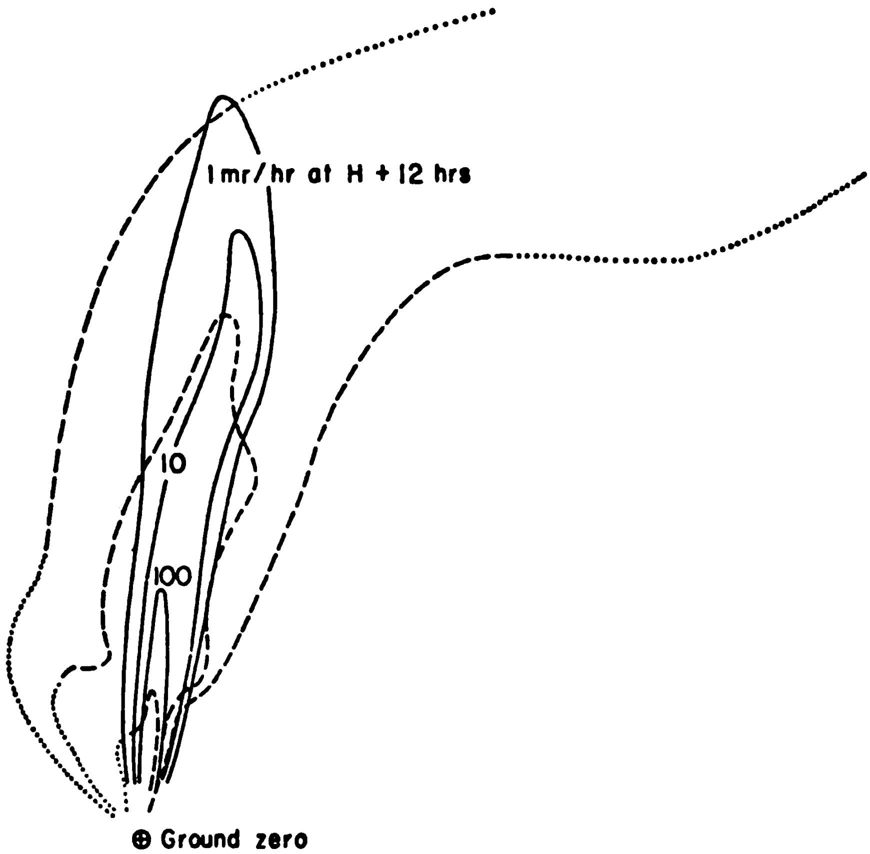

FIGURE 5.—The observed fallout distribution (dashed lines) and the pattern computed by LASL-UCRL using winds predicted at H-2 hours. May 5, 1955.

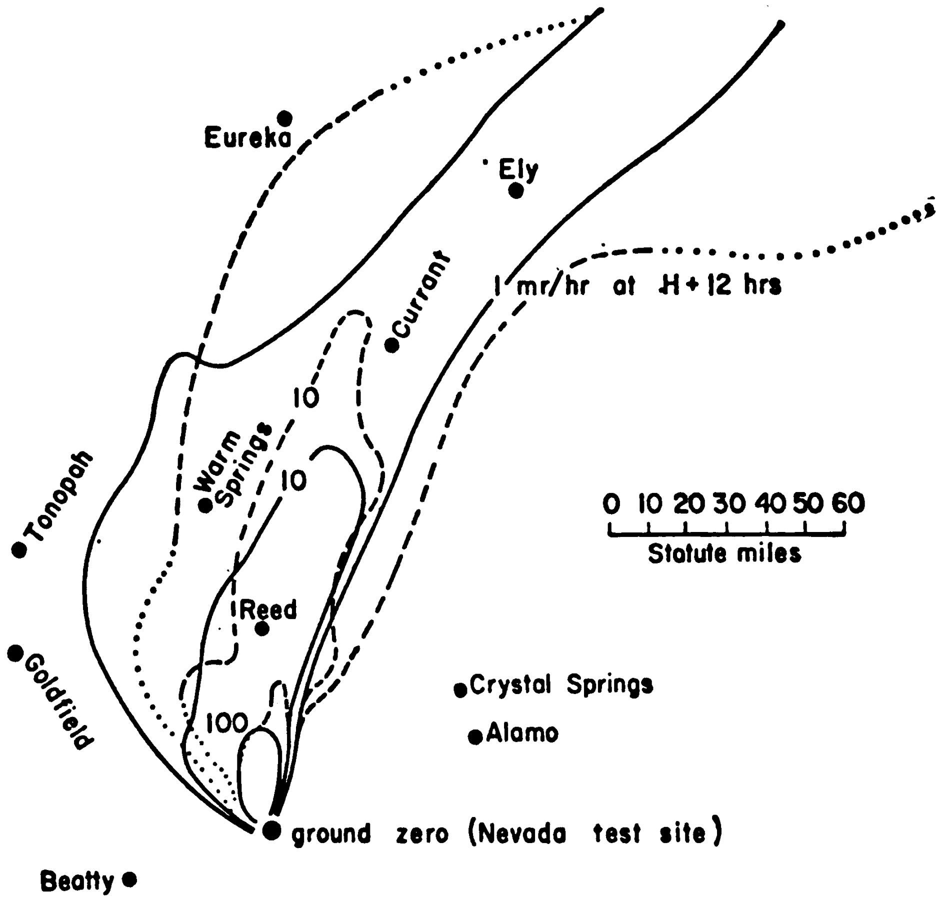

FIGURE 6.—The observed fallout distribution (dashed lines) and the pattern reconstructed by the Weather Bureau using a hand computation with time and space variation of winds (solid lines). May 5, 1955.

TABLE 3.—*Mean absolute bearing change of integrated winds*

Time interval (hours)	Integrated wind from surface to—		
	20,000 feet	40,000 feet	50,000 feet
3	12°	7°	6°
6	22°	15°	13°
12	33°	28°	----------

It will be noted that the bigger the thickness of the atmosphere considered in forming the integrated wind the smaller is the shift of the wind. This probably reflects the fact that wind shifts at one level may sometimes be partially canceled by opposite wind changes at another altitude. Another lesson to be learned from this study is that the statistics of the wind at one level cannot be relied upon to give reliable information about the statistics of the integrated wind, which must combine the effects at many levels.

A recent study of the predictability of fallout for the Nevada test site has been made by Jack Reed of the Sandia Corp.[36] Here the variability of the wind, the forecasting accuracy, the length of the forecast period, etc., are all considered in order to given an estimate of the degree of confidence with which the fallout can be put into an uninhabited "safe sector." This approach to the problem is one which should be taken more often in meteorology, since it demonstrates that any weather forecast should have a prabability assigned to it—a probability which is always less than one.

THE DYNAMICS OF FALLOUT

So far a great deal has been said about the final fallout pattern and how it is computed. A very important feature of the pattern from a practical standpoint

[36] Reed, J. W.: Estimating Safety Probabilities From Fallout Forecasts for Nevada Test Site, Sandi Corp. report SC-4073 (TR), February 1957.

is the *time* at which the fallout reaches various parts of the pattern. Clearly, the fallout cannot all occur at once, since it takes some time for the particles to reach the ground, and while they are falling they are carried with the wind. Thus, the fallout around ground zero starts very quickly, whereas the fallout miles away may not start for hours. (For example, the island of Rongelap did not receive its fallout until some 4 to 6 hours after shot time.[7])

Recall that, for a surface burst of more than a few kilotons yield, most of the radioactive debris is in the mushroom cloud. When the yield is several megatons, this mushroom cloud rises into the stratosphere,[1] and so even the relatively infrequent larger particles, of 1,000 microns diameter and over, take from 30 to 40 minutes to fall back to the ground. It appears that there are some few radioactive particles which escape from the mushroom while it is rising and are left behind in the stem cloud, and these will, of course, find their way to the ground sooner, in the downwind direction.

In order to demonstrate the time of arrival of radioactivity at points relatively close to ground zero, the Naval Radiological Defense Laboratory[9,10] and the Army Chemical Corps[11] have designed equipment which records the fallout as a function of time. Though their respective instruments were designed independently, they both work on essentially the same principle: A small tray or container is uncovered for a certain period of time (say, 5 minutes), then covered again. Automatically the next sampler is uncovered for its sampling period, and so on. It should be mentioned that both sets of instruments remained closed for the first minute after shot time, to allow the shock wave to pass the sampling station.

A large number of such fallout versus time measurements were made at the time of the Castle shot 1, and a few had been made earlier at the Ivy Mike test by NRDL. When all the results using 5-minute sampling times (20 cases) are plotted up one is impressed, first of all, at the erratic nature of the results. This is probably due to the fact that the samples are made with small areas and small time intervals, and therefore do not give results which are entirely representative of the fallout at that location.[27]

The next thing which one notices about the results is that the majority of them show *no fallout for the first 30 minutes;* the average time of arrival for all stations which received any fallout was 28 minutes. These stations were located at distances from ground zero ranging from 8 to 30 miles. In visualizing these distances, recall that the Ivy Mike cloud had a radius of about 5 minutes of 10 miles, and at 10 minutes it was nearly twice this. For the Castle shot 1 the radius at 10 minutes was about 30 miles, and still growing. Thus, all the stations represented were literally in the shadow of the great mushroom cloud—though none were in the initial part of the stem.

The few stations which did apparently receive fallout earlier may have had something wrong with their mechanism (as would appear to be the case where two nearby stations give completely opposite results), or they were in a direction from ground zero which allowed them to be dusted by the material from the crater area which was born by the low level winds. This latter explanation appears to be reasonable, since we know that a certain small fraction of the radioactivity produced does reside in the stem cloud at relatively low altitudes.

It is therefore tempting to visualize the fallout as a slowly descending blanket, with a diameter roughly the diameter of the mushroom cloud. The blanket starts its fall as soon as the atomic cloud stabilizes (about 4 to 6 minutes after burst time) and touches the ground over a large area simultaneously. While this mushroom material undoubtedly represents the major fallout, some material from the stem may reach the ground sooner, and the direction of this immediate fallout from the stem would be determined by the mean wind in the lower levels, below, say, 20,000 feet.

Following this early arrival of the radioactive debris the fallout pattern is laid out in a more or less orderly way and spreads in the direction of the integrated winds. To illustrate how the pattern grows with time, figures 7 and 8 show the growth of a hypothetical 1 megaton pattern under 2 very different wind conditions. One shows how it grows under a condition where the winds are moderately strong and all in the same general direction. The other shows how one grows under a low wind condition. In the first case the debris is spread rapidly in a ribbon across the country. In the second case the debris continues to fall in the vicinity of ground zero for many hours. Neither of these wind conditions is particularly unusual, and there are naturally an infinte number of possible intermediate cases.

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[27] See ref. 10.

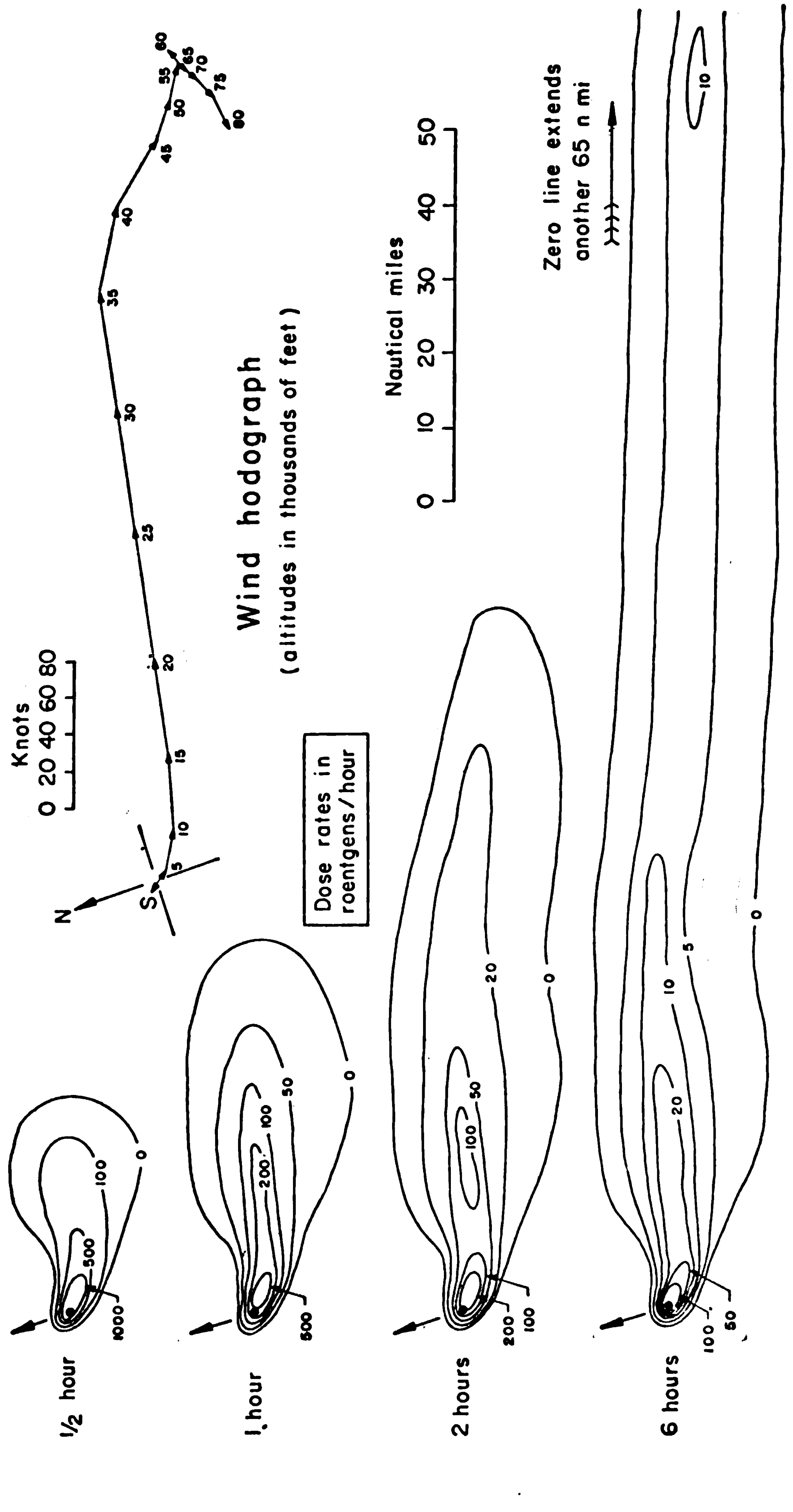

FIGURE 7.—Calculated fallout from a 1 MT surface burst with a two-thirds fission yield under a "high wind" condition. Winds are those for San Francisco on June 15, 1954.

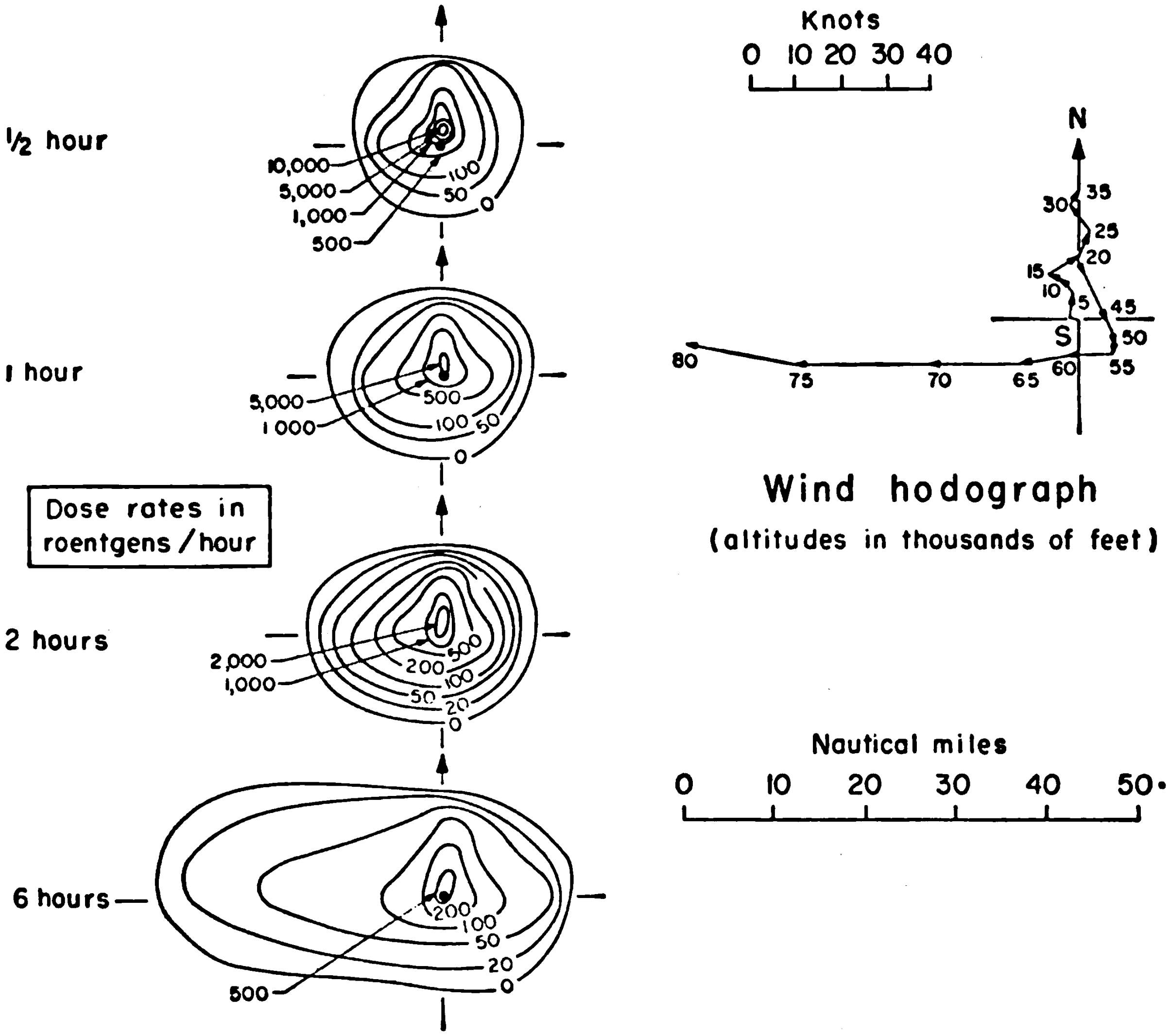

FIGURE 8.—Calculated fallout from a 1 MT surface burst with a two-thirds fission yield under a "low wind" condition. Winds are those for Atlanta on June 15, 1954.

FALLOUT FROM A BOMBING CAMPAIGN

No discussion of fallout would be complete without some discussion of the results of a bombing campaign, in which many bombs are set off against a target system with a large number of widely dispersed aiming points. Such a target system might be, for example, the industrial complex of the United States, or its system of airbases, providing targets which are located in a more or less random manner over the entire country.

The natural laws governing the fallout from such a campaign are the same as those governing the fallout from one burst. The difference lies in the fact that now the fallout patterns overlap in places and reinforce each other. Furthermore, where the ground zeros are fairly close to each other the fallout is more or less independent of the wind direction, since it makes little or no difference which bomb causes fallout on a given spot—such an area is "blanketed."

A number of studies have been made of such campaigns,[28 29] and a technique has been developed by Greenfield for estimating on a probabalistic basis the results of fallout from multiple-bombs dropped randomly in a large area.[30] One such study, in which the hypothetical fallout was computed for an attack on the United States under a rather typical meteorological situation, was performed by Charles K. Shafer, headquarters, Federal Civil Defense Administration, Battle Creek. It was done in connection with the FCDA's Operation Sentinel.

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[28] Davidson, H. D., J. B. Green, J. B. Phelps, C. D. Stolzenbach: Fallout as a Threat from Attack by Manned Bombers, Operations Research Office, Johns Hopkins University, ORO-R-17, appendix C, September 1956 (secret).

[29] Rapp, R. R.: Fallout Computations for Operational Studies, Rand Corp., RM-1753, July 1956 (secret, R. D.).

[30] Greenfield, S. M.: Radioactive Contamination from a Multibomb Campaign, Rand Corp., RM-1607, January 1956 (secret, R. D.).

Though this represents just one particular combination of events, it is instructive to see what would have happened under this hypothetical attack, according to Shafer.

In this exercise about 250 nuclear (or thermonuclear) weapons with "damage zones" ranging from 3 to 5 miles were dropped on cities, industrial targets, and airfields through the United States. The combined fallout pattern from all these bombs is shown in figure 9. The details are contained in an unpublished report by the FCDA, and the following are some of the general conclusions which were drawn with regard to the effect of such an attack on the United States population:

	Dead	Injured	Uninjured
1st day	36,000,000	57,000,000	58,000,000
7th day	51,000,000	42,000,000	58,000,000
14th day	61,000,000	31,000,000	58,000,000
60th day	72,000,000	21,000,000	58,000,000

These numbers are based on 1950 population figures. Those dead on the first day were presumably killed by the immediate effects of the bombs, i. e., mostly blast and thermal effects. The subsequent rise in fatalities reflects the delayed effects of radiation damage, coupled in many cases to external injuries. While one should not take these actual numbers too literally, their orders of magnitude and the trends shown here are fairly realistic. In particular, the indication that fallout might account for a large number of deaths—nearly as many died by the immediate effects—is pertinent. In actuality, many of the "uninjured" ones would be caught by the fallout as they tried to move about. Clearly, however, such figures can only be illustrative, since the behavior patterns of the population would have a tremendous effect on the casualties due to radiation. While the meterorologist can predict to some extent the fallout patterns, he can hardly be expected to predict whether or not the population will be trained and provided with adequate shelters before such an attack.

Dr. KELLOGG. I am with the Rand Corp. at Santa Monica, Calif., at the present time. I am head of what we call the geophysics group. The geophysics group is composed to a large extent of meteorologists and atmospheric physicists, and we have been interested in studying the subject of radioactive fallout for a number of years.

I feel somewhat inadequate for the job of presenting all the material which I want to present today, partly because it is a complicated question, and partly because I feel that there is still some difference of opinion among meterologists on the details of this question of close-in fallout. I hope that I can not only reflect sort of a consensus of opinion, and my own opinion, but also indicate where we feel that we need to have more information on the subject of close-in fallout.

Before I start, I would like to make three rather general statements which in a sense are threads of the whole thing which I am presenting.

The first is one which I think you have already sensed from the testimony of Dr. Graves, to the effect that radioactive fallout is a major effect from an atomic explosion. I therefore feel that we should make all the pertinent facts available to the public and to the military on this question because one can't consider an atomic explosion and its effects without considering radioactive fallout.

The second point I would like to make very briefly is this.

Chairman DURHAM. May I ask a question at that point? Has your company been doing this all the time—making the information available to the public and also to the military?

Dr. KELLOGG. We have tried to very hard. In the January issue of the Journal of Meterology, for example, the work on close-in fallout

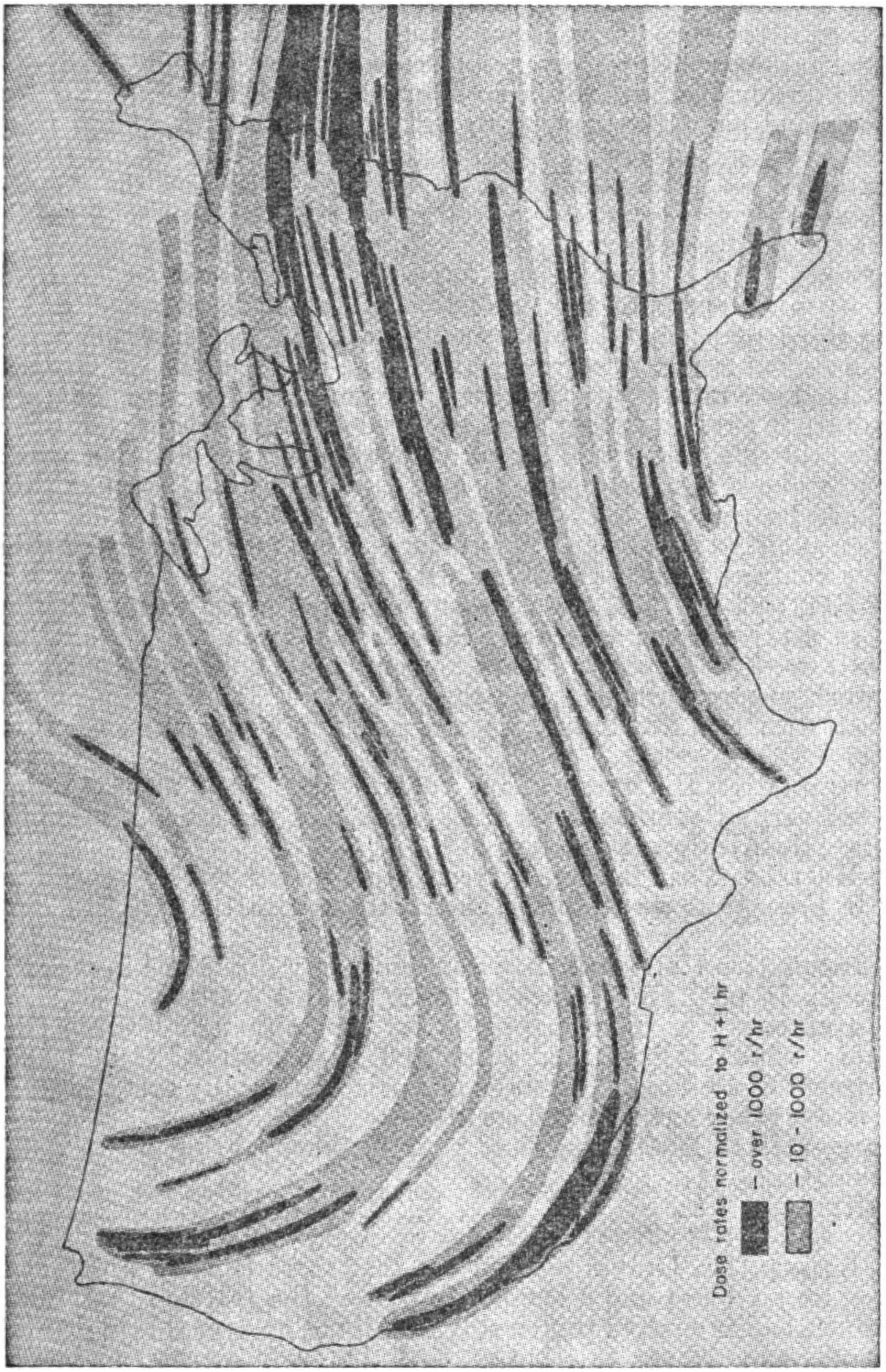


FIGURE 9.—Fallout condition computed by the FCDA for Operation Sentinel.

which our group has done was summarized. It is an article which appeared in what you might call the official United States meteorological journal by Dr. Rapp and Mr. Greenfield and myself. There have been other outputs from our group that have to do with other facets of fallout which we have published as fast as we could get them into the open. We have made an effort in this direction.

The second point I was going to make has to do with feeling that I think every meteorologist would share with me, that we are often charged with an impossible job of predicting exactly how the atmosphere will behave over a long period of time in the future. I think one of the points to be made is that there is always an element of uncertainty in a meteorological forecast. This should be kept in mind when we speak of the prediction of fallout patterns.

The third point that I think should be made in connection with close-in fallout is that when we speak of close-in fallout, as Dr. Graves pointed out, we must try to figure out how much of this material does come down in close-in fallout, because this determines what is left over to go worldwide. So I will spend a little bit of time defining what we know about the fraction which falls out close in, because this will have bearing on the worldwide problem, too.

Representative HOLIFIELD. Your company has made a study of this under a contract with the AEC or with the Defense Department?

Dr. KELLOGG. In 1953, our company accepted a contract with the AEC to study various aspects of fallout. This ran for 3 years. I believe it was 3 or 3½ years. We no longer operate under this contract. Our work is now primarily for the Air Force. Under our prime contract with the Air Force, we are continuing our work on this matter.

Representative HOLIFIELD. Your reports have been made to the Atomic Energy Commission for the 3 years, and you are now making reports to the Air Force; is that right?

Dr. KELLOGG. That is correct; yes. Most of our work is now for the Air Force, but we maintain close liaison with the AEC in our work.

Representative HOLIFIELD. Are you under any directions in regard to security in testifying before us today on this matter?

Dr. KELLOGG. No. I am happy to say that although I wrote the testimony which is here, and submitted it to both AEC and the Department of Defense, it has been cleared. Essentially everything I wanted to say they have allowed me to say.

Representative HOLIFIELD. Does your testimony bring up to date your findings?

Dr. KELLOGG. Yes.

Representative HOLIFIELD. You may proceed.

Dr. KELOGG. Dr. Graves pointed out that there is a big difference between an air burst and a surface burst and the fraction that falls out. Since he has covered this so ably, I will not go over this in detail. You understand about this business of the surface material being mixed in the fireball when the detonation is on the surface.

In the case of a tower shot, which is sort of an in-between case, the fraction which comes down is variable, in the complete report, in order to demonstrate how variable this is, I have taken some numbers which were given to me by Mr. Nagler, of the Weather Bureau, who has made a very careful analysis of the fraction which fell out from

five detonations, all of about the same yield. All had about 15 kilotons yield, and all were on the same height of tower.

The interesting thing was that they varied over a rather wide range in the fraction which came down. This, I think, is probably due to the fact that the meterological conditions and the way in which the tower was made, the amount of material around the test device, and so forth, all varied.

Representative HOLIFIELD. Do you mean by that that the fallout was uneven and in some places there was a heavier dose than others?

Dr. KELLOGG. This is true, of course. It is not just laid down uniformly. The thing which I was speaking of at the moment was the total fraction which comes down in the first 24 hours in the part of the country which is carefully monitored so we can keep track of it, in other words.

Representative HOLIFIELD. There was a great variation in the reading of your instruments?

Dr. KELLOGG. When all the information from all the instruments was in and analyzed, and the Weather Bureau or the Health and Safety Division was able to analyze this, they were able, as it were, to count up all the radioactivity over the entire area, and get a total budget. They knew how much went into the atmosphere. They were able to see how much came down. They could say that this was some fraction of the amount produced.

Representative HOLIFIELD. But that was in the nature of a fraction of the total fallout, and it was not a measurement of the degree of the dose in that area, or was it both?

Dr. KELLOGG. It was both. In order to determine the fraction which fell out, the thing which is measured is the dose.

Representative HOLIFIELD. What was your variance between the high dose and the low dose?

Dr. KELLOGG. Later on I can show you a chart—I am glad I came prepared with a chart—showing an example of just how it does vary in the test area.

Representative VAN ZANDT. Doctor, we have been talking about the fallout coming down and going up. For a kiloton yield, how many pounds of radioactive debris does it lift into the stratosphere?

Dr. KELLOGG. I don't know the number. You mean for a surface burst.

Representative VAN ZANDT. Yes; for a surface burst.

Dr. KELLOGG. I don't know exactly. I think Dr. Graves mentioned something about a ton per kiloton or something like that.

Representative VAN ZANDT. Dr. Graves said the figure he used would be debatable. The reason I ask the question is that Dr. Libby some months ago made a statement in which he said that for every 20,000 tons of TNT yield 2 pounds of radioactive fallout is lifted into the heavens. Then he went on to explain that within a matter of weeks most of it will have fallen out. Then he talked about the megaton yield, and how it was lifted into the stratosphere, and that it may remain there from a few seconds to 10 years. Would you concur in such a statement?

Dr. KELLOGG. These numbers, I think, are a little confusing, about the 2½ pounds per kiloton. I don't know what he was referring to Perhaps he meant radioactive debris.

Representative VAN ZANDT. That is correct.

Dr. KELLOGG. The important thing seems to be that the fraction of the total debris which is produced does not depend on the yield as much as it depends on the height of the burst. What I mean to say is this. We have a case in Nevada of a surface shot for which we could measure the dose around the countryside and make an estimate of the fraction of that low-yield device in Nevada which came down. The various estimates are produced here. It looked as though something like 80 or 85 percent of the material from that low-yield surface burst came down somewhere in the first 24 hours. Then in the Pacific, although it has been very hard until recently to estimate what this fraction was, during the last test a system for monitoring the oceans has been developed and by an analysis of this ocean monitoring again we are able to make a rough estimate of the fraction which comes down in 24 hours.

Again, although the estimates vary, a good estimate seems to be around 80 or 85 percent for surface bursts. This is over a very wide range of yields.

Representative COLE. When you speak of a surface burst, do you include a tower test?

Dr. KELLOGG. No; I do not. A tower seems to produce less fallout fractionwise. An air burst produces virtually no close-in fallout. Mind you, my subject is close-in fallout, so I will stick to this amount that comes down in the first 24 hours.

Representative HOLIFIELD. You may proceed.

Dr. KELLOGG. The meteorologists who are concerned with a study of fallout are naturally interested in how to keep track of the debris. I don't propose to give a lesson on how to compute fallout patterns. I think, though, that it would be constructive for the committee to know that these are four main schools of thought on how to predict or reconstruct fallout patterns.

The four main schools of thought—and I will show a chart in just a moment—all require one input, and that is the wind information. In order to tell the direction the fallout goes, the wind must be observed, and if it is a prediction, the wind must be predicted. This is an essential ingredient to any fallout calculation, obviously. In actually doing this, the wind all the way up from the ground to the height of the atomic Cloud has to be taken into account, since the particles start up high when the cloud stabilizes, and start to fall, and they spend a certain length of time in each layer as they wall. So the distance which they travel on their way to the ground will, of course, be the cumulative effect. We refer to this cumulative effect in terms of the integrated wind, as we measure it.

This integrated wind, or cumulative wind, up to some altitude is so essential to a fallout calculation that the Weather Bureau, at the request of the FCDA, has recently gone to a system of teletype messages twice a day from about 70 stations in which a kind of integrated wind appears in the regular wind transmission. This is to make the integrated wind immediately available in any Weather Bureau station in the country.

Representative COLE. Would you explain what you mean by integrated wind? I do not understand.

Dr. KELLOGG. Yes. I If I can take just a moment, I can draw a picture. Dr. Graves mentioned that we have all been teachers at one time or another, and we reach for a blackboard whenever we can.

The use of the word "integrated" is perhaps a little too fancy. It really means we are just adding winds together to get some sort of resultant wind.

If we can represent the wind at any one level by a vector, a particle traveling through this layer will travel in the direction of the vector, and it will go a distance proportional to the length of the vector. If it travels through this layer and falls down into the next layer, it will find itself then traveling with the wind at that layer. So it will start curving and follow that new path. Perhaps the wind at the next layer down will be different again. After we have added the winds at a number of layers together, we might have a curving path something like that, representing the horizontal projection of the particle's trajectory. We have added vectors, and we have gotten the resultant as the particles travel through a number of layers and finally reach the ground. This is what we would call the integrated wind, or the effective wind, the path which the particle finally took.

Representative COLE. Does that mean the mean of the wind influences?

Dr. KELLOGG. This is the total effect of the wind on the particle as it fell from the place it started to the ground. You might think of it as the "mean." I think that it would be fair to call it the mean effect.

This is an essential ingredient to any fallout calculation. I have a chart here which will show the four main schools of thought for computing fallout that I mentioned. Very briefly I will go over these various schools of thought.

Here I have sketched in a little vector addition such as I have on the board. This is the kind of thing which is very easy to compute. In general, no matter where the particles came from in the atmosphere, one of the integrated winds will be a line connecting the origin of the vector plot with the end of one of these vectors. Just by inspection of this little diagram you can see that no matter where the particle started from, it has got to be in this sector between the dashed lines. So this is just the simplest kind of fallout calculation. It merely says there is a "danger sector," and somewhere in there there will be fallout.

Chairman DURHAM. You are talking to what height?

Dr. KELLOGG. Our usual radiosonde wind flights go to 60 to 80 thousand feet, and with a big effort they can be made to go higher. This is usually high enough to establish where the danger sector will be. If very large yields were to be involved one might be interested in winds still higher than our usual radiosondes can go.

The next school of thought, if I can refer to it as that, is known as the "idealized pattern." I have not seen the new book which AFSWP has prepared, which you have in your hand. AFSWP has been one of the chief exponents of the idealized pattern. Essentially it started with the observation in the early days of fallout that fallout patterns often look sort of cigar-shaped, and it was tempting to try to characterize all fallout patterns as a simple elliptical shape with a circle around ground zero. Then various rules were established for shaping them, making them fatter or skinnier or longer or shorter, depending on the yield or the wind.

The idealized pattern is a very useful method where one wants to characterize fallout for planning purposes. But it has not found much

acceptance where one is interested in a prediction, because the predicted patterns are apt to be more unideal.

Representative COLE. Ideal from what standpoint?

Dr. KELLOGG. They can be characterized by a simple ellipse like this.

Representative COLE. I still don't understand what is intended to be the ideal.

Dr. KELLOGG. Idealized in the mathematical sense, I guess, in that you can characterize it in a sort of perfect shape.

Another method for predicting fallout patterns and one which appeals to meteorologists—because every meteorologist when he makes a forecast of weather looks at the present weather pattern and searches his mind (or his files if he is well organized) to try to find something like it in the past, and then he will say to himself: "What happened in the past will probably happen again, so I will use this back pattern or analog as a prediction tool. I will simply see what happened the day following that previous case which was like the case today."

An analog method could be used for predicting fallout if we had a big collection of fallout patterns, and the winds that went with them, and then we would just match winds and scales taking into account the yield and we would be able to have a fallout prediction. However, we have not had very many actual fallout patterns to look at. So we really have not been able to build up a real file of analogs. The only file of analogs that we can draw on is one which is computed theoretically. As a matter of fact, the Rand Corp. has published, unclassified, something which we call "the catalog of fallout patterns," on the basis of which one can begin to use an analog method for prediction.

The most complete characterization of fallout is usually started with what is known as a "fallout model." A few agencies have taken the bull by the horns and have set up very complicated computing schemes for tracing each particle down to the ground from each level, each particle size, and adding up the effects on the ground. Of course, no one computing scheme could actually trace each particle, but there are shortcuts, and various agencies have developed practical computing schemes based on some kind of a fallout model, which reproduces the fallout as accurately as it can be done by theoretical methods.

Representative HOLIFIELD. Let me ask you this question. There are a number of these patterns in the AFSWP book.

Dr. KELLOGG. Idealized patterns.

Representative HOLIFIELD. There is an idealized pattern here. There are different kinds of patterns in here. I notice that in 1954 high yield explosion at Bikini that it gives a long pear shaped pattern. It starts out with a 5,000 roentgen yield and it goes at the end of 60 miles to 3,000, and at a little over 100 miles it is 2,000 roentgens, at 130 miles it is 1,000 and at 160 miles it is 500. That is at 36 hours.

Dr. KELLOGG. Mr. Chairman, these are probably cumulative doses, aren't they?

Representative HOLIFIELD. Yes, over the 36 hours. I was going to ask you about that. Dr. Graves spoke today about receiving 200 roentgens. As I remember the description of that accident, it was just for a moment. The question I want to ask you is this: Would 200 roentgens received in an instant be equivalent to 200 roentgens received over a longer period?

Dr. KELLOGG. This is a biological question. I prefer not to answer this in any detail. My biologist friends tell me that there is a certain amount of leeway there in the time in which one could accept it. If you get it within a relatively short time like a few hours, it is equivalent to getting it all at once. This is something which I think the biologists should comment on.

Representative HOLIFIELD. Very well.

Dr. KELLOGG. In order to give you a feel of what actually happens under fallout conditions, I have three charts which I can go through very quickly. They were prepared following the open or civil defense shot on May 5. This is a chart which was prepared by Mr. Nagler, who has made a detailed study of the fallout from a number of the tests in Nevada.

This first chart (p. 114) shows the fallout from the May 5, 1955, civil defense or open shot, which was roughly 30 kilotons on a tower. This is a map showing a few of the landmarks, Goldfield, Tonopah, Warm Springs, and so forth. You notice the scale of miles here, 60 miles as the total scale. In red is the observed fallout as deduced from an extensive system of road monitoring and from a few aircraft observations in that area. You see it goes out several hundred miles.

This little red line here is 100 milliroentgens per hour at 12 hours. The next red line is 10 milliroentgens per hour at 12 hours, and the outside one is 1 milliroentgen per hour at 12 hours. These blue lines here were a noble attempt to reconstruct the fallout taking into account all the wind observations at the time, and a careful synoptic analysis of the fallout. Here you can see the blue and red lines following fairly close to each other, the 10 and 10 and the 100 and 100. You can see the close-in fallout was reproduced quite well. In fact, the general curvature of the pattern toward the east was reproduced very well. It is important to note the curvature toward the east, because this is the kind of thing I was talking about when I said that a meterological forecast is a tough thing.

Representative COLE. Before you take the chart down, does the blue line indicate the forecast of the weather people with respect to the wind?

Dr. KELLOGG. No. This is a reconstruction. The next chart (p. 113) shows a forecast.

Representative VAN ZANDT. Did this fallout move as a mass and did it continue to move as a mass, or did it break up eventually?

Dr. KELLOGG. In this case it continued to move as a mass. In other words, it started falling here close to ground zero first, and then it was laid down in a fan shape curving to the east. It occurred earlier close in and later and later as you go along in the pattern. Heavy particles were landing close in, and lighter particles which drift longer landed further out.

This next chart (p. 113) is a prediction. This is the Weather Bureau's prediction, using the winds predicted at 2 hours before shot time. I think this is the kind of thing that one would expect. Very good verification in close. After all, this is where it is important. But then it was pretty hard apparently, in this case to predict the later shift, which must have occurred as much as 12 hours later.

Representative COLE. Is your scale the same in this chart?

Dr. KELLOGG. Yes. The scale is exactly the same. It is the same map. The red lines are exactly tracing the red lines you saw before.

Just to show the Weather Bureau is not the only outfit making predictions, this was the Los Alamos Scientific Laboratory and the University of California Radiation Laboratory prediction. They also have a forecast team of meterologists. Here again the prediction made at 2 hours before the shot time showed the early fallout within the hundred milliroentgen per hour at 12-hour line to be fairly well verified, at least in the direction in which it went. Again they did not get the curvature of the later fallout.

Chairman DURHAM. What would be your observation as to the accuracy there in the predictions by the Weather Bureau and the other outfit? It looks to me they are off quite a bit in the prediction, because the observation line there cuts back pretty quick, and the other continues on up.

Dr. KELLOGG. The early part, as I say, in both cases was fairly well verified, but neither of them anticipated the shift of the wind which occurred later on. I think this is what one would expect. The meteorologists don't fool themselves as to how well they can predict the wind. There are a number of studies of this matter. One of the best ones recently was by the Air Weather Service, which gives actual wind statistics and forecast statistics. Recently, Jack Reed, a meterologist with the Sandia Corporation, has made a study of this situation and applied it directly to Nevada, the purpose being to try to assign some kind of probability to a forecast made a certain number of hours before shot time. Meteorologists recognize that any forecast is a kind of probability. It is an educated guess. This effort by Reed is a very noble effort to actually assign the right kind of probability to such a forecast, so that the people who have to use the forecast can know with what certainty the forecast was made.

Representative COLE. How do you account for the fact that the forecast of the direction of the fallout was reasonably accurate, but the forecast of the breadth or width of the fallout was quite inaccurate?

Dr. KELLOGG. I don't know the details. I did not sit down and go through exactly the assumptions that were made in each of these models by these people. I can only say that it would have something to do with the model they took, that is: How big a cloud they assumed, which would determine how wide the pattern was; how the radioactivity was distributed with height; the fraction which fell out, which we were talking about earlier—any of these might not have been predicted accurately. As I mentioned earlier we are uncertain about this fraction when we are firing in a tower. Any of these assumptions could have had an effect on the width of the predicted pattern.

Representative COLE. But the analyzers did know in advance the estimated yield of the test, did they not?

Dr. KELLOGG. Yes. Even though you may know the yield for a tower shot, you may not know the fraction of this yield which takes place in the early fallout with any accuracy, nor how it is distributed with height and particle size. These could have accounted for this changing shape.

Representative VAN ZANDT. Both groups had the same data as far as weather was concerned in that part of the world.

Dr. KELLOGG. Yes. They both used the same wind prediction.

Chairman DURHAM. In other words, they are pretty good up to a hundred miles, but beyond that it is not too accurate?

Dr. KELLOGG. That is the way it looks here, and that is the way it would always tend to look where we have a difficult forecast situation. This is probably a very light wind condition. The distant parts are really rather unimportant. I might mention here, as I recall, that the farthest extension of the 100 milliroentgen per hour line on this chart represents a "lifetime dose"—that is, the accumulated dose you would receive if you stood out in the open from the time it came down to infinity—of 9 roentgens. At this point on the 10 milliroentgen per hour line it is much less. It is a fraction of a roentgen.

Representative HOLIFIELD. You have not given us the strength of that particular weapon.

Dr. KELLOGG. About 30 kilotons on a 500 foot tower.

Representative VAN ZANDT. Doctor, are you in a position to tell us how long you actually followed that cloud?

Dr. KELLOGG. I am sure it was followed. I don't remember the details. An attempt is made for radiological safety purposes to trace where the cloud went by meteorological analysis. This is something which we have done quite a bit of at Rand. I don't remember whether we analyzed this one particularly or not. It is possible to do it by just analyzing the winds. It is also possible to do it by monitoring it by aircraft.

Representative VAN ZANDT. Is that your field, monitoring the cloud by aircraft?

Dr. KELLOGG. No, that is not.

Representative COLE. Would you repeat the dosage at 10 miles out? Would you state again what that is?

Dr. KELLOGG. Let up put this first chart (p. 114) back up which has the scale of miles. Let me make sure I have the right numbers here.

This point here—the furthest extension of the 100-milliroentgens-per-hour, 12-hour line—represents an infinity dose of 9 roentgens. That is about 30 miles from ground zero.

Representative COLE. Tell me what you mean by an infinity dose of 9 roentgens.

Dr. KELLOGG. By reconstructing the pattern and also by certain instruments which note when the thing starts, we can tell when the debris arrives at the ground. It doesn't all arrive at once, but it arrives within a relatively short period of time. Then, if we had an instrument which just simply counted roentgens, and it was hung on a post 3 feet above the ground and stayed there from then to doomsday, it would fiinally accumulate 9 roentgens. That is what we mean by infinity dose. Of course, most of this 9 roentgens would be accumulated in the first few days.

Representative COLE. What is the influence which determines the period of accumulation other than wind?

Dr. KELLOGG. The wind determines when it starts. The total dose then depends on the amount which comes down, and when it came down.

Representative COLE. Suppose it got there at this point and there was no wind at all.

Dr. KELLOGG. It would hardly get there if there were no wind at all.

Representative COLE. I still do not understand what you mean by a 9 roentgen perpetuity dosage.

Dr. KELLOGG. I can draw it perhaps as a time plot. (At the blackboard). This is the dose rate in roentgens per hour on the vertical scale. Here is the time on the horizontal scale. We said this was for a point about 30 miles out from ground zero. Suppose there was a 10-knot wind, so about 3 hours after shot time we begin to get fallout. The dose rises at 3 hours, and suppose it falls for the next hour and then stops. That is probably what would have occurred, fallout occurring for about an hour while the cloud is passing by. Then decay starts. This is radioactive decay at the rate that Dr. Graves gave, according to the time-to-the-1.2 power law, where time is measured from shot time. If this were the rate at 3 hours, and if we go to 7 times that, or 21 hours, it would be down by a factor of 10. After another 7 times 21 hours, whatever that is, the dose rate would be down to a hundredth. If we counted up the total number of roentgens, that is, multiply the dose rate times the time for each time interval and sum over all the intervals, we would get a cumulative dose. If we calculated this out on the tail of the curve to an infinite length of time, we have what we call an infinity dose. As you can see from here, most of this infinity dose is obtained in the first day or so in this case.

Representative COLE. I think I understand. At least I do better than I did before.

Dr. KELLOGG. I admit it is a difficult concept at first, but it is one which the people who are working with fallout sometimes use. They prefer to use an infinity dose instead of a dose rate at some time. It is merely a matter of what you want to talk about.

Representative HOLIFIELD. Dr. Kellogg, how far are you on your summary? I understand that you can be with us tomorrow, and, if it is very long, I want to carry you over until tomorrow. If it is short, since it is 5:30 and the members have to get back to their offices——

Dr. KELLOGG. I would like to take a little bit longer, 10 or 15 minutes, if that is all right for you, so perhaps tomorrow would be better. What I have to present still, I think, is fairly pertinent.

Representative HOLIFIELD. We do not want to cut you out of any time. I suggest that we start with you tomorrow and, in the meantime, it will give the staff some time to look at your prepared presentation, and we may have some more questions for you.

Dr. KELLOGG. This was a good stopping point, anyway.

Chairman DURHAM. I might say this is my first lesson in meteorology.

Representative HOLIFIELD. The Chair will announce that the committee will resume its hearings tomorrow morning in room 457 in this building. There will also be a 2 p. m. session tomorrow. Wednesday, we will come back to this room again. The meeting stands adjourned.

(At 5:25 p. m., Monday, May 27, 1957, a recess was taken until Tuesday, May 28, 1957, at 10 a. m.)

Your article on World Wide Travel of Atomic Energy Debris will be inserted at this point.

[Reprinted from Science, September 14, 1956, vol. 124]

WORLD-WIDE TRAVEL OF ATOMIC DEBRIS

L. Machta, R. J. List, L. F. F. Hubert[1]

For centuries meteorologists have thought of exploring large-scale atmospheric circulations by means of tracers. The literature describes how man has successfully tracked fluorescent particles to a distance of 100 miles,[2] used radioactive tracers across the United States,[3] and followed volcanic ash and forest fire smoke over distances of the order of 1000 miles.[4] Only the dust from a major volcanic eruption, such as Krakatao, has been tracked on a truly global scale.

During two of the nuclear test periods in the Pacific Proving Grounds of the U. S. Atomic Energy Commission, sufficient radioactive debris was thrown into the atmosphere to be deposited in both hemispheres. Measurements of the deposited radioactivity were obtained from exposed sheets of gummed film. The details of the network and the sampling and measurement techniques have been described by Eisenbud and Harley.[5] It should be noted, however, that the deposition of particles on the adhesive surface depends either on the presence of precipitation or, in dry weather, on turbulence to assist the impaction of the particles on the horizontal surface of the paper. It is thus possible to have a cloud of radioactive particles pass two stations simultaneously and have only the station with rain note the presence of the particles overhead. The gummed-film method of collection is recognized as being as crude as it is simple.

The nuclear explosions are treated in this article, the Mike shot on 1 November 1952 and the Bravo shot on 1 March 1954. The shots were similar in that both are described as having had energy in the megaton range, both were detonated at or near the earth's surface on a coral island, and both had atomic clouds that penetrated into the stratosphere. To the meteorologist, the main difference of interest between the two events is the season.

WINDS

The winds acting on the two atomic clouds at the time of detonation are illustrated in Fig. 1. The wind structure has been estimated, when necessary, from observations at nearby locations and times. On both days the tropopause was found at an altitude of about 55,000 feet, and it separated winds blowing from different directions. The easterly winds above the tropopause increased in speed to the highest altitude of the available wind information for the Bravo shot, while for Mike the easterly winds decreased in speed and ultimately changed to westerly winds. The easterly winds in the trade-wind layer, the moist maritime air mass lying near the sea, extended up to about 20,000 feet during the detonation of the Mike device, while for the Bravo shot they were below 10,000 feet. Between the trade-wind layer and the tropopause, one normally finds westerly winds. During the Mike shot these westerlies were temporarily interrupted and became southerly winds, while for the Bravo shot they were toward a more normal bearing.

In Fig. 2 is found the approximate area covered during the early days by that part of the nuclear cloud from the Mike shot which was located below the tropopause. The shaded areas in Fig. 2 have been deduced from meteorological considerations alone, and, in many cases, are subject to considerable uncertainty. Shading was discontinued when the meteorological data no longer warranted any reasonable estimate of the path. The light winds and sparsity of upper-wind observations have made tracing the upper tropospheric portion of the Mike cloud

[1] The authors are on the staff on the U. S. Weather Bureau, Washington, D. C.
[2] R. R. Braham, B. K. Seely, W. D. Crozier, Trans. Am. Geophys. Union 33, 825 (1952).
[3] R. J. List, Bull. Am. Meteorol. Soc. 35, 315 (1954).
[4] H. Wexler, Weatherwise 3, 129 (1950).
[5] M. Eisenbud and J. H. Harley, Science 124, 251 (1956).

particularly uncertain. For this reason, the time of passage across the North American mainland is unknown. Tracing was discontinued on 7 November. The tradewind portion of the nuclear cloud appears to have split south of Japan, the upper portion (near 20,000 feet) curving around a Pacific high cell and entering the United States about 9 November.

The estimated meteorological path of the Bravo cloud is shown in Fig. 3. The upper tropospheric portion of the nuclear cloud was traced to the Central American area by about 5 March, and an offshoot extending northward into the United States at about 20,000 feet was detected approximately 1 week later.

Differences between the paths of the Mike and Bravo clouds are evident from Figs. 2 and 3. In part, the differences are seasonal and in part due to the specific meteorology for the shot days. Thus, in November the mid-tropospheric westerly winds are not as strong as they are in March, and they are located farther north, on the average. Further, in November one finds an anticyclonic circulation not far from the Marshall Islands which is not typically present in March. The shallowness of the trade-wind layer during the Bravo shot is an example of a feature unusual for the region during any season.

There has been no attempt to track the stratospheric portions of the atomic cloud because of the sparsity of wind observations at these altitudes. Evidence from numerous isolated high-level winds, not necessarily obtained during the periods of the two nuclear tests, suggests a path that would travel around the earth at about the same latitude as the point of origin. It is interesting to note that in no case was it imperative to rely on stratospheric transport of the nuclear debris to account for the earliest arrival at any point, for the transport of the nuclear cloud in the troposphere appeared to account for the first observations of radioactivity.

An attempt to determine the earliest arrival time at the ground at each point of observation has been undertaken. The results, which are shown in Figs. 2 and 3 as the number of days after the shot day, should in many cases be viewed with caution. First, in many of the stations in the Southern Hemisphere, the deposited activity was so low that it made the arrival date almost meaningless. Second, despite elaborate precautions, it is likely that some gummed films were contaminated during handling. Finally, as noted in the second paragraph the apparent arrival time of the cloud at many stations coincided with rainfall, suggesting that the nuclear cloud may have been overhead some time earlier but that precipitation was required to bring its activity to earth.

FALLOUT

It is noted that, in accordance with the meteorological estimates, the fallout over the United States progressed roughly from west to east during the Mike shot. Fallout from the Bravo event did not appear at the West Coast stations in the United States until 2 weeks after one of the cloud protuberances entered the central United States. Of perhaps greatest interest, although also of greatest doubt, are the comparatively early arrival times in the Southern Hemisphere. Thus, for example, a literal interpretation of the chart reveals that every station in the Southern Hemisphere showed an earlier arrival time than did the United States West Coast stations for the Bravo case. Also of interest are the comparatively late arrival times for the mid-Pacific stations west of the Hawaiian Islands during the Mike fallout. These stations were south of one branch of the nuclear cloud and north of the other.

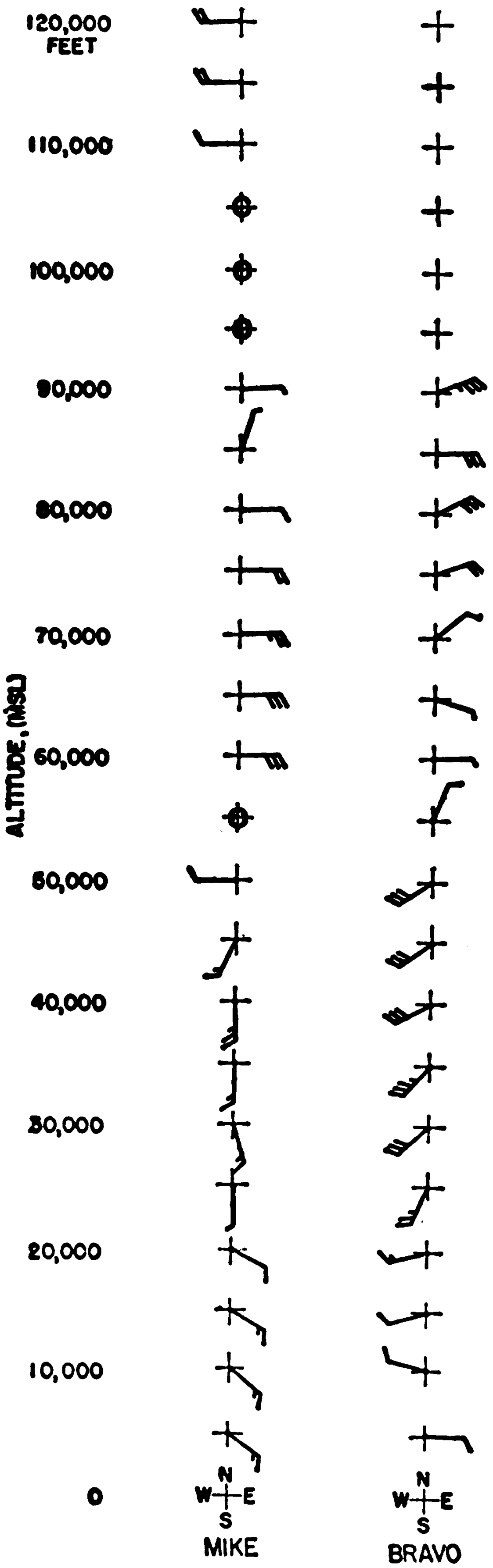


Figure 1.—Upper winds at shot time. Arrows blow with the winds, and barbs indicate wind speed; full barb, 10 knots; one-half barb, 5 knots.

The actual fallout at each station and an analysis of the data are shown on Figs. 4 and 5. The units are cumulative decayed beta activity for the first 35 days following each event and are approximately equivalent to millicuries per 100 square miles (the values have not been corrected for the efficiency of the gummed film.) Several features that differentiate the two maps should be noted. First, an average value for all United States and Canadian stations was obtained for the Mike shot, as opposed to values for individual stations during the Bravo shot. Second, the isolines located between points on the West Coast of the United States and points in the Western Pacific Ocean are also based on fallout observations obtained from transport vessels for Bravo. Finally, as is evident, the network was expanded between the two events, primarily in an attempt to locate stations in rainy areas. In many cases, when the period of record is incomplete or the data are suspect, parentheses have been placed around the number. No attempt has been made to reconstruct the isolines for the fallout that occurred within the first 24 hours of the shot.

The comparatively small values obtained at the Southern Hemisphere stations especially during the Mike shot, are immediately evident from the fallout maps. The northern part of the Northern Hemisphere, however, received equally small depositions. The distribution of fallout for the Pacific stations appears to be consistent with the features of the meteorology described, although the branching of the cloud south of Japan in the Mike pattern is based only on scanty observational evidence.

It is apparent that radioactive debris produced by nuclear explosions does not possess all the desired attributes of a tracer for studying global circulations. Information concerning the magnitude and distribution of the radioactivity that remains airborne after the initial fallout is not available. The debris, being particulate, is washed out of the atmosphere and cannot be strictly treated as a conservative property. Thus, for example, the depositions in the Southern Hemisphere may have been low because most of the debris was rained out as it passed southward through the Intertropical Convergence Zone. In addition, the most effective sampling program for the debris provides only the crudest measure of the fallout. Yet, despite these limitations, it appears that the meteorologist can obtain useful information by operating such a network of gummed films during nuclear test periods. Although it is not proposed that special nuclear tests be undertaken for meteorological purposes, it seems reasonable to expect even greater value from future tests using an expanded network and having detonations at other locations and times.

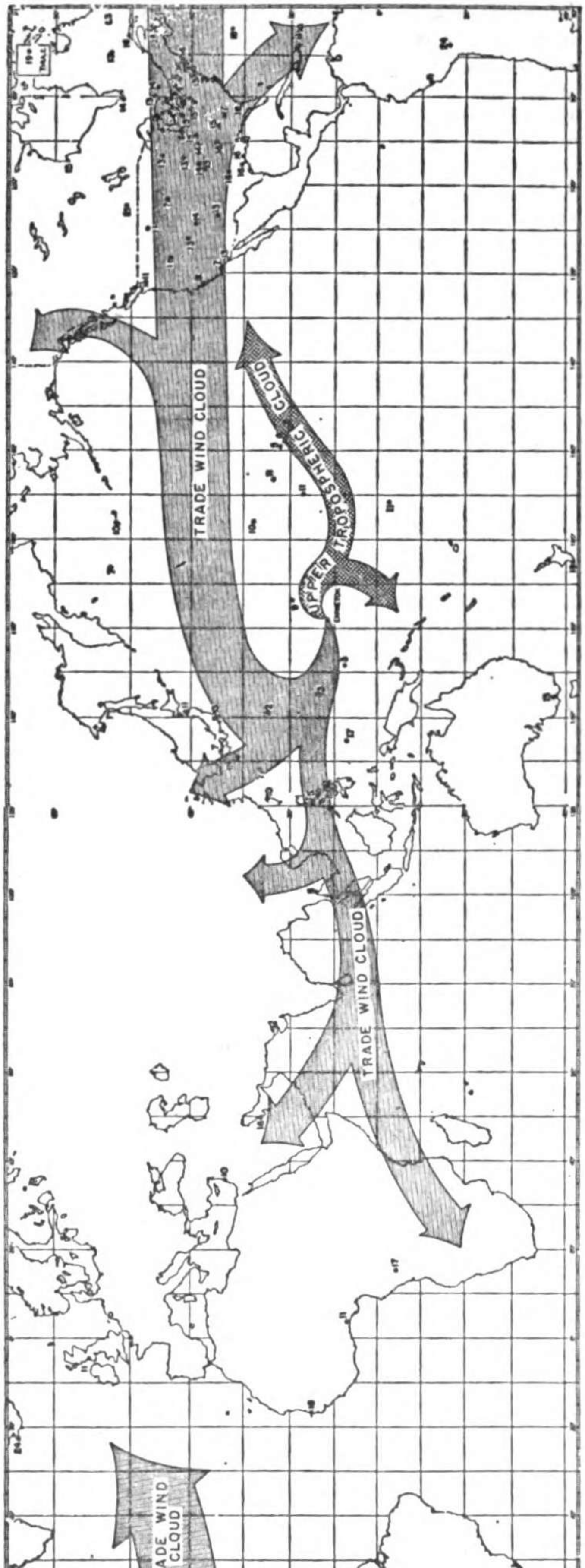


FIGURE 2.—Early history of the Mike cloud. The figures indicate the number of days between detonation and the first ground observation of fission products.

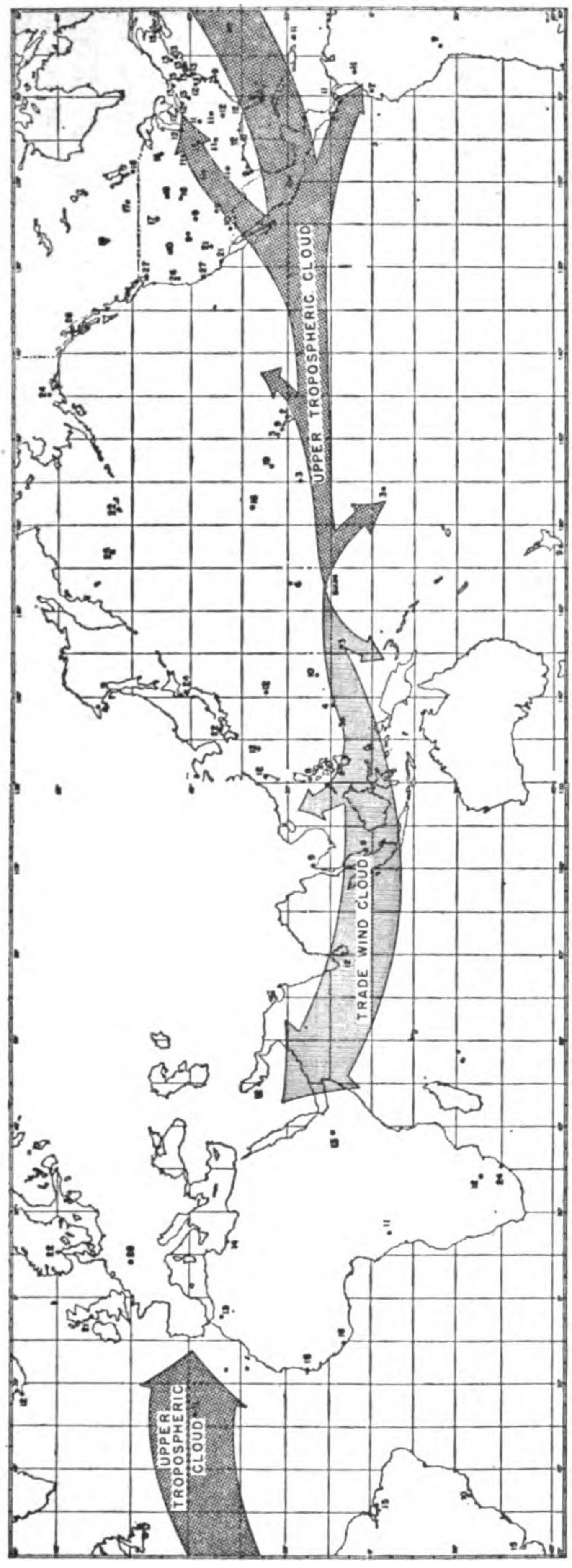


FIGURE 3.—Early history of the Bravo cloud. The figures indicate the number of days between detonation and the first ground observation of fission products.

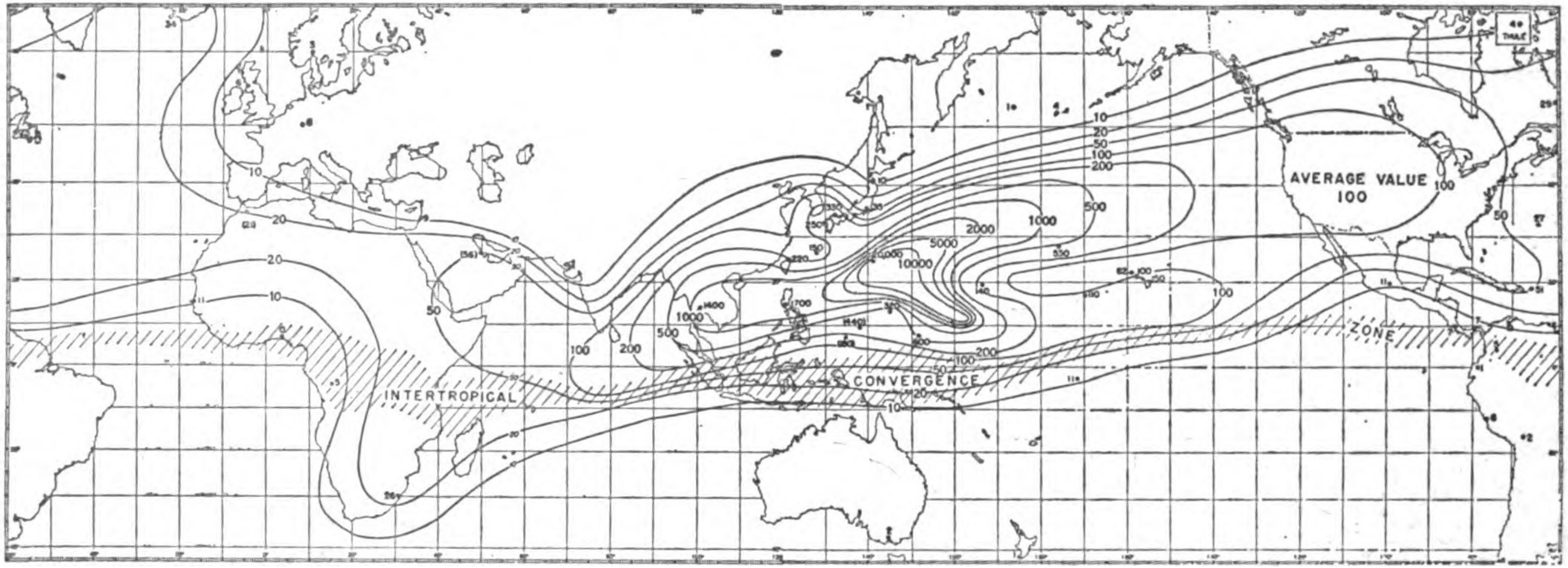


FIGURE 4.—Total radioactive fallout from the Mike cloud in the period from 2 to 35 days after detonation, in millicuries per 100 square miles. Hatching indicates the approximate November position of the Intertropical Convergence Zone, the belt of low pressure that tends to separate Northern and Southern Hemisphere air near the surface of the earth.

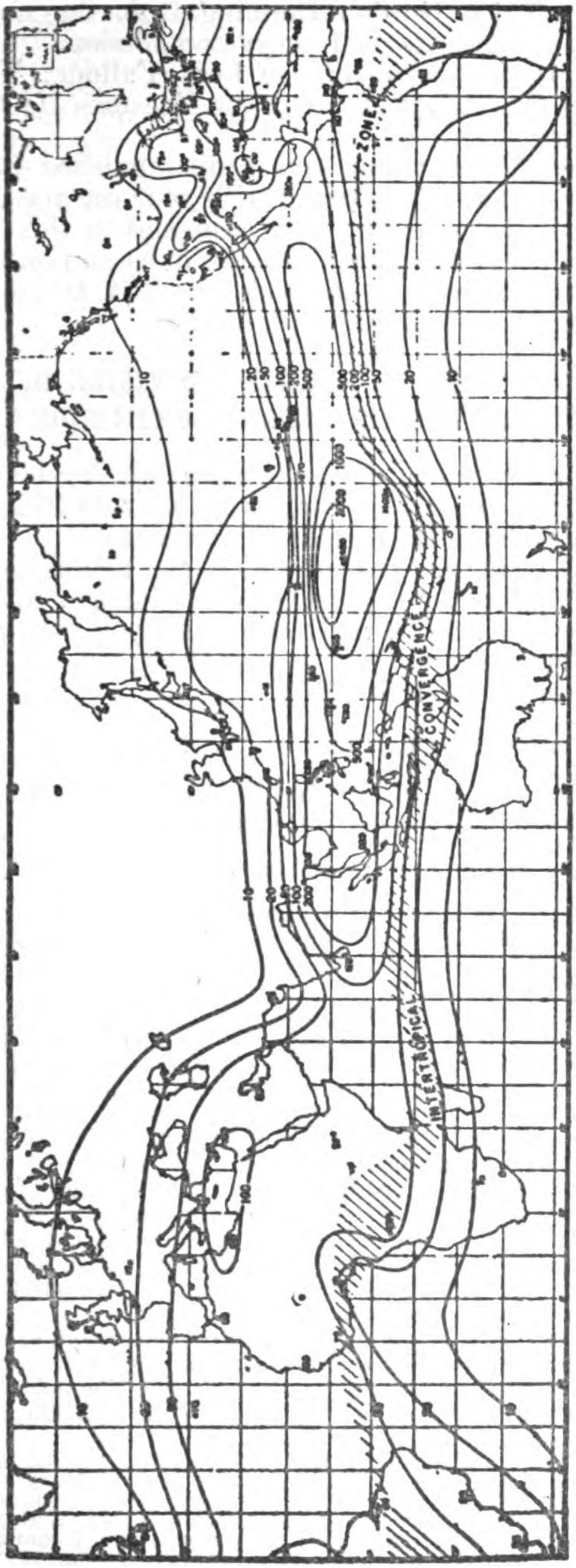


FIGURE 5.—Total radioactive fallout from the Bravo cloud in the period from 2 to 35 days after detonation, in millicuries per 100 square miles. Hatching indicates approximate March position of the Intertropical Convergence Zone, the belt of low pressure that tends to separate Northern and Southern Hemisphere air near the surface of the earth.

FIGURE 3

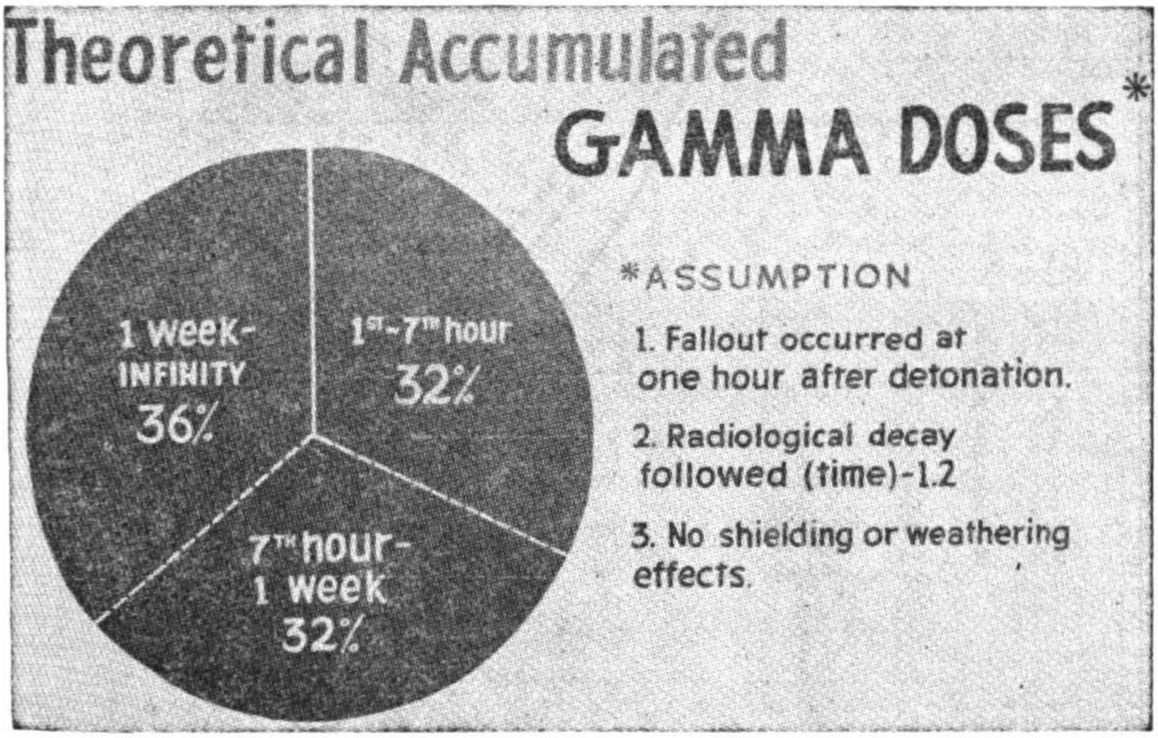
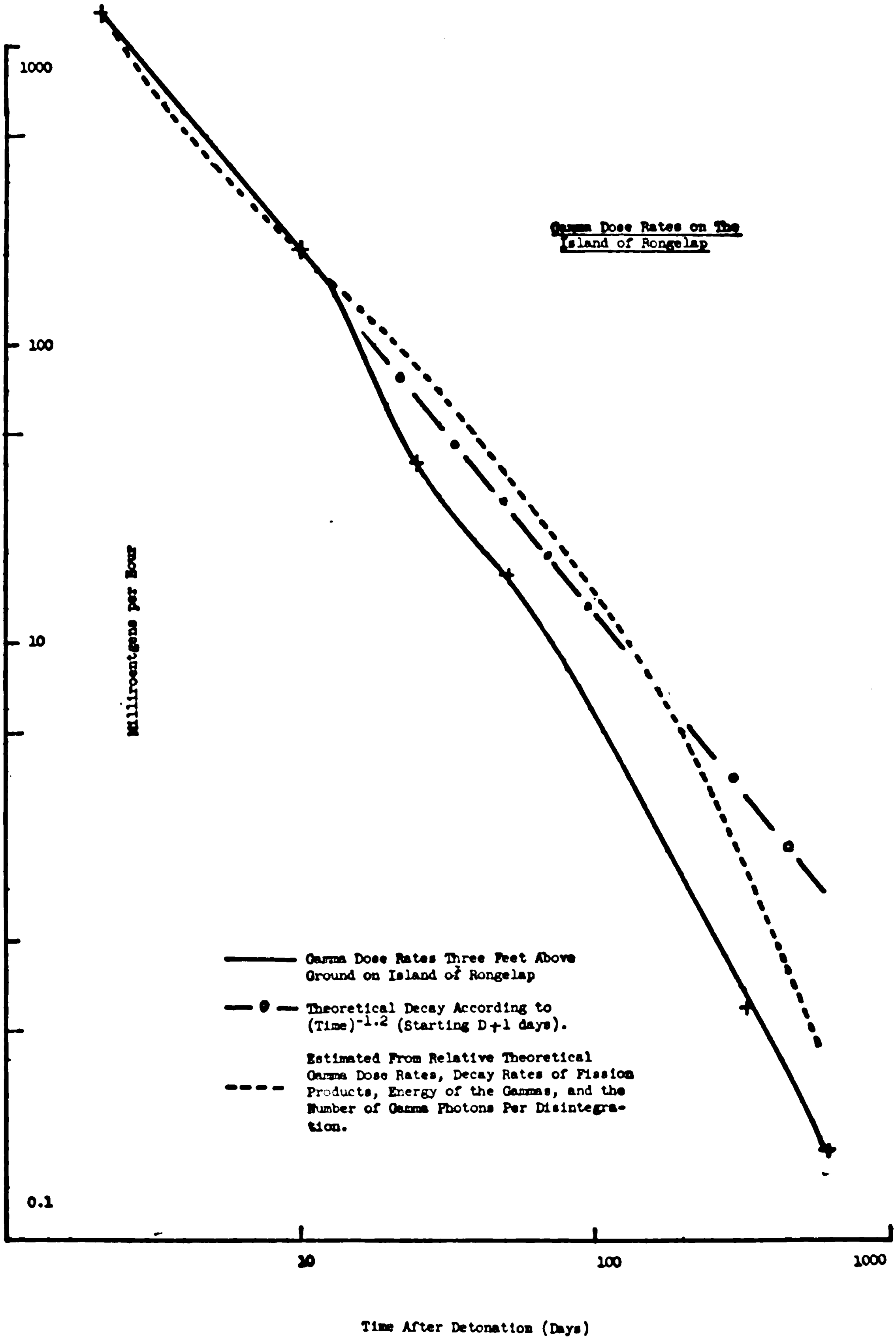

Theoretical Accumulated
GAMMA DOSES*
1 week-
INFINITY
36%
1ST-7TH hour
32%
7TH hour-
1 week
32%
*ASSUMPTION
1. Fallout occurred at one hour after detonation.
2. Radiological decay followed (time)-1.2
3. No shielding or weathering effects.

FIGURE 4


Gamma Dose Rates on The Island of Rongelap
1000
100
10
0.1
Milliroentgens per Hour
10
100
1000
Time After Detonation (Days)
Gamma Dose Rates Three Feet Above Ground on Island of Rongelap
Theoretical Decay According to (Time)$^{-1.2}$ (Starting D+1 days).
Estimated From Relative Theoretical Gamma Dose Rates, Decay Rates of Fission Products, Energy of the Gammas, and the Number of Gamma Photons Per Disintegration.

Discussion

The action of requesting personnel to remain indoors is predicated on the principle that the radiation levels are below those established for evacuation and that this action could reduce the amount of contamination of personnel and reduce somewhat the whole-body gamma dose. (See appendix A for estimates of reduction in whole-body gamma dose.) The actual "savings" healthwise have to be balanced against possible adverse public reaction.

The principal gain in requesting personnel to remain indoors is to prevent or reduce the amount of atomic debris that may actually fall on the body or clothing. Since the peak of fallout usually occurs shortly after the start of fallout, it is important that prompt decisions and actions be taken. Thus, by necessity, the most practical criteria upon which to base a decision are gamma dose rate readings, which are in turn related to the amount of fallout.

Beta dose to skin.—The most immediate solution might be to establish lower permitted dose rate levels at later times after detonation. However, if a series of dose rates are established for increasing times after detonation so that their relationship follows $t^{-1.2}$, then the doses delivered in X hours (before the material is washed off) will be greater for earlier times after detonation. If one were sure of the time that the fallout material was to remain in place, then a scale of dose rates versus time after detonation could be made to yield the same total dose over the X hours. Since there is obviously no set time period for duration of contact that would be valid for all cases, one might assume the worst case where the material remains in place until its activity has decayed to an insignificant level. Dose rates could then be approximated, to yield a given infinity dose, by:

$D=5At$ where: D=infinity dose; A=dose rate at time "t".

If the above discussion is accepted, then the remaining question is to set the infinity dose. Here, we must be clear that whereas the measurements taken by the monitors, and the data upon which action will be decided will be gamma dose-rate readings, the point of principal concern is the beta dose delivered to the basal layer of the epidermis (assumed as 7 milligrams per square centimeter). The ratio of emission of beta to gamma is a function of time after detonation and follows no simple relationship. Further, this ratio at any given time after detonation has not been firmly established. One report suggests the following data:

Time after detonation:	*Beta/gamma*
72 hours	157/1
168 hours	156/1

These data were obtained from a cloud sample rather than actual fallout material, and were a measure of surface dose on a plaque using a "dosimeter type beta-ray surface ionization chamber."

The method of collection suggests the possibility that the thickness of material on the plaques may be less than that to be expected from the amount of fallout that would be of concern when estimating probabilities of beta burns. This would result in a different angular distribution of the betas influencing the beta dose rate in the direction of a higher value for the plaques.

Another report indicates a beta to gamma ratio of 130 to 1 based on theoretical computations. A third report suggests a radically lower ratio; however, there may be some doubt as to its conclusions since the ionization chamber, used to measure gammas only, had a wall thickness of 1 mm. of bakelite which "* * * excluded a small part of the total gamma dose present, as well as a large, but unknown, fraction of the beta." (The range of 0.35 Mev. betas is about 100 mg./cm.^{2} or approximately 1 mm. of bakelite.) For our discussion here, we will assume a *surface* beta to gamma ratio of 150 to 1.

In estimating the beta dose to the basal layer of the epidermis, one may refer to the work of Henriques.[7] He exposed the skin of Chester White pigs to plaques containing different radioisotopes. Pertinent data are abstracted as follows:

Isotope	Energy	Surface dose required to produce recognizable trans-epidermal injury (roentgen-equivalent-beta)	Estimated amount of radiation that penetrated skin to a depth of 0.09 mm. (roentgen-equivalent-beta)
Yttrium 91	1.53	1,500	1,200
Strontium 90	.61	1,500	1,400
Ytrrium 90	2.20		

The average maximum energy of the beta particles from fallout material varies with time but will be assumed to be roughly comparable, in respect to depth dose, to yttrium 91 or Sr–90—Y–90. Since the gamma dose at a depth of 7 mg./cm.^{2} would not be significantly different from the surface gamma dose, the ratio of 130 to 1 for beta-gamma will be assumed at the basal layer of the epidermis.

(One experiment with sheep, using Sr–90—Y–90 plaques, showed that 2,500 reps at the plaques' surface produced ulceration in 1 but not another of 2 sheep.[8] On the other hand, 1,000 rads delivered to tissue depth of 7 mg./cm.^{2} from a P^{32} 1-inch diameter disk (type of animal not stated) produced tanning, prolonged erythema, and desquamation.)

It is to be remembered that the above discussion was first based on *surface* gamma dose rates whereas the monitors will be making their gamma measurements at a height of 3 feet. Past field experience has indicated that the gamma reading from ionization-type survey meters at ground level is about 50 percent higher than at 3 feet. Therefore, if it be assumed that a ground level gamma reading of a survey meter is equivalent to a surface dose rate, the ratio of beta dose rate at 7 mg./cm.^{2} to gamma dose rate at *3 feet* is about 200 to 1.

Another approach to estimating the ratio of beta dose rate at 7 mg./cm.^{2} to gamma dose rate at 3 feet is as follows: Assuming a uniform distribution of 1.0 megacurie per square mile of gamma activity, the dose rate reading from an infinite field is about 4.1 roentgens per hour.[9] Calculations given in appendix B indicate that a like concentration of fallout material will produce about 430 reps per hour at 7 mg./cm.^{2} This suggests a beta to gamma ratio of about 100 to 1 which is about a factor of 2 lower than the first approach. Added support to this latter method of estimating beta doses is found in appendix C.

Such considerations may be fraught with pitfalls. For example, the above discussion implies a uniform distribution of fallout material. Obviously this is not correct, but how far this deviates from the facts and to what extent this influences the results is difficult to assess. Calculations indicate that the production of recognizable beta burns from a single particle requires a high specific activity. (See criteria III for discussion.) It may well be, however, that the particles of fallout are close enough to have overlapping of radiation fields and thus require significantly lower specific activity of the particles to produce beta burns. This hypothesis has support in that even the most superficial beta burns of the natives exposed to fallout following the March 1, 1954, detonation showed a general area affected rather than small individual spots. On the other hand, the cattle and horses exposed near the Nevada test site showed burns over areas only about the size of a quarter. Even though these may not have been produced by single particles, they do represent less of an area effect than suggested for the natives. Also, radioautographs of the fallout in areas outside the Nevada test site suggest the occurrence of individual particles with nonoverlapping of radiation fields. However, in nearby areas where the fallout was relatively heavy, there was a definite overlapping of the fields.

[7] Effect of Beta Rays on the Skin as a Function of the Energy, Intensity, and Duration of Radiation. Henriques, F. W. Laboratory Investigation. Vol. 1, No. 2. Summer 1952.

[8] Comparative Study of Experimentally Produced Beta Lesions and Skin Lesions in Utah Range Sheep. Lushbaugh, C. E., Spalding, J. F., and Hale, D. B. LASL, November 30, 1953. (Unclassified.)

[9] Effects of Atomic Weapons. 1950.

With our present knowledge it should be stated that due to the particulate nature of fallout it would not be possible to establish reasonable and operationally workable criteria that at the same time would guarantee that there *never* would be an occurrence of a beta burn.

If one were to accept the assumed beta to gamma dose rates of about 100–200 to 1 (measured under the conditions given above), this might mean an infinity beta dose of 1,000 to 2,000 reps to the basal layer of the epidermis when the whole body infinity gamma dose was 10 roentgens. Of course, the fallout material may be removed before the infinity dose is delivered; yet, on the other hand, it is not improbable that it could remain in the hair for essentially this length of time. In the case of a 1-hour fallout, almost one-half of the dose would be delivered in the next 24 hours.

The efficiency of a surface for collecting and holding the fallout material is important. It is not surprising that the highest dose rate readings as well as biological effects were noted on the hair of the natives and also on parts of the exposed body where perspiration was present. Further, it was observed that even one layer of light cotton material was sufficient to protect against beta skin damage in most cases.[10] This was due probably not to the relatively small attenuation of the betas by the clothing but rather to the physical situation of holding the radioactive material at some distance from the skin, which effect would be relatively large.

An added consideration is the possibility of high beta doses delivered to personnel from the fallout material lying on the ground and other surfaces. If the highest degree of contamination considered under this policy is safe when in direct contact with the skin, then the beta dose from an equally contaminated ground will not be hazardous. (See criteria III for discussion on unequal contamination on personnel.) However, it is true that the contamination may exceed the amount to deliver dose rates given in graph II and yet not be great enough to consider evacuation. Some personnel may not go indoors, and those who did will eventually be released from this restrictive action and then may walk around in a relatively highly contaminated area. Because of the more limited range of the beta, the location of greatest concern is the lower legs.

One report estimates a beta to gamma dose rate ratio of about 75 to 1 at 10 centimeters above the ground.[11] Under criteria I it was recommended that consideration be given to evacuation when the gamma dose rate reading at 3 feet was, for example, about 6.2 roentgens per hour at H+3 hours. Roughly, this would correspond to about 575 reps per hour of beta at 10 centimeters. Of course, this activity decays, and also it is presumed that personnel would be sent indoors, at least for a few hours. On the other hand, it strongly suggests that biologically significant doses may be delivered to the feet if not protected. Skin lesions were frequent on the bare feet of the natives evacuated during Castle. This probably was a combination of beta dose from material on the ground and from that scuffed up over the bare feet and then clinging to the skin. (No lesions were observed on the bottom of the feet, undoubtedly due to the thick epidermis.) It would be expected that normal closed-type footwear (as compared to open sandals) would afford adequate protection to the feet from such high beta doses as discussed here. There is still no guaranty that beta radiation from material on the ground will not deliver significant biological doses to the ankles and perhaps lower legs, after personnel are released from staying indoors. For example, if the beta dose at 10 centimeters above the ground is 575 reps per hour at H+3 hours, it would be about 250 reps per hour 3 hours later and 160 reps per hour 6 hours later.

One further possibility is the accumulation of radioactive material around the ankles and lower legs resulting from normal walking about the area. This is discussed under criteria III.

Data on human exposures.—The work of Henriques[12] suggests that at the depth of 0.09 mm. in living porchine skin (maximum thickness of epidermis) that "1,400±300 roentgen-equivalent-beta" (delivered over short periods of time so that they may be assumed to be instantaneous) is required to produce recognizable transepidermal injury. The curve of biological damage rises rather

[10] ITR–923. Study of Response of Human Beings Accidentally Exposed to Significant Fallout Radiation, Cronkite, E. P., et al. May 1954.

[11] AD–95 (H). An Estimate of the Relative Hazard of Beta and Gamma Radiation from Fission Products. Condit, R. I., Dyson, J. P., and Lumb, W. A. S. NRDL 1949. (Unclassified.)

[12] Op. cit.

sharply so that at a dose of just under 2,000 reps (at 0.09 mm.), the epidermis may be expected to exfoliate and in the majority of cases go on to develop chronic radiation dermatitis persisting for months.

The preceding discussion suggests that, using the gamma dose rates listed in these criteria, which are based on an estimated 10 roentgen infinity gamma does, as high as 2,000 reps might be delivered to the basal layer of the epidermis over a period of time covered by the lifetime of the radioactive material.

There have been instances where the calculated infinity gamma dose in areas where personnel were present around the Nevada test site have reached 12 to 15 roentgens, but there have been no known cases of beta burns in these areas. The number of persons involved in these areas of highest contamination was relatively small, perhaps a few dozen, and with an observed duration of fallout of about 1 hour it is possible that they were not in a position to receive the full fallout. Likewise, minute areas of the skin may have been so affected yet not detected or reported. In other areas encompassing some 2,000 people the infinity gamma dose was about 8 roentgens and no instances of beta injury appeared.

The estimated whole-body gamma dose to natives evacuated from the island of Utirik following the March 1, 1954, detonation at the Pacific Proving Ground was about 15 roentgens for a period of about 3 days, but no beta burns appeared. It is fair to assume here that direct contamination took place due to their mode of living, including housing that was quite open to air currents. Gamma dose rate readings were taken over the bodies of the natives at about H+78 hours both on the beach and after boarding the ship. On the beach the personnel readings averaged about 20 mr. per hour gamma (but this probably included some contribution from the ground contamination), and after wading through the surf and boarding the ship the levels averaged 7 mr. per hour gamma.

The 18 natives on Sifo Island, Ailinginae Atoll, received an estimated whole-body gamma dose of 75 roentgens in about 2¼ days. Of these, 14 later experienced slight beta burns, 2, moderate burns, and none showed epilation.

In the case of the Rongelap natives, the estimated whole-body dose was about 170 roentgens in about 2 days. All 64 natives later experienced beta burns to some degree from slight to severe, and over half of the natives showed epilation from slight to severe.

The 16 natives from Rongelap evacuated directly by air to Kwajalein had personnel gamma dose-rate levels generally 80 to 100 mr. per hour although 1 was as high as 240 mr. per hour and 1 as low as 10 mr. per hour (at H+ about 55 hours). The remaining 48 natives evacuated by ship were reported to have personnel readings that "averaged" 60 mr. per hour before decontamination. The picture is further confused because some of the natives had bathed and some had not before the arrival of the evacuation team.

Most of the 28 United States service personnel stationed on Eniwetok Island, Rongerik Atoll, received about 40 to 50 roentgens, based on film badge readings. Three members of the group who were located for part of the time in another section of the island were estimated to have received somewhat higher doses. Seventeen of the twenty-eight personnel showed only slight, superficial lesions with one questionable case of epilation. It should be pointed out that the personnel were in metal buildings during some of the fallout time and for most of the time thereafter until evacuation. This reduced the direct contamination as well as the whole-body gamma dose. A film badge hanging on the center pole of a tent at one end of the island read 98 roentgens. Calculations based on dose-rate readings at another part of the island indicated somewhat lower doses, if personnel had remained in the open for the period of time from fallout (about H+7.5 hours) to evacuation (at about H+34 hours). Upon arrival at Kwajalein 1 personnel gamma dose rate reading was as high as 250 mr. per hour at about H+35 hours.

The above data do suggest that there may be possible a rough bracketing of gamma-beta doses versus beta burns. On the one hand, the natives from Utirik received an estimated whole-body gamma dose of 15 roentgens and showed no evidence of beta burns. On the other hand, the natives on Sifo Island, Ailinginae Atoll, received about an estimated whole-body gamma dose of 75 roentgens, with 14 personnel showing slight burns, 2, moderate burns, 2, no burns, 3 with moderate epilation, and 15 with no epilation. In addiiton, Rongelap natives received 170 roentgens whole-body gamma dose, and about 90 percent showed some degree of lesions and 56 percent some degree of epilation.

It is to be recalled that: (*a*) The natives probably were out of doors and received the full fallout; (*b*) the oily hair, seminaked, perspiring bodies, including bare feet, and lack of bathing for most, would tend to collect and hold the fallout material; (*c*) the time of delivery of essentially all of the doses was 2 to 3 days. Further, it may be speculated that the fallout on the more distant island of Utirik (about 300 statute miles) would consist of smaller particles and also perhaps lesser possibility of overlapping of radiation fields from these particles.

Some of the relevant data are summarized in table II. Due to the uncertainty of the degree of exposure of personnel on Rongerik to the direct fallout, this group is not included. It is to be immediately emphasized that any comparisons made or implied in the table are at the most only semiquantitative. Table II will be referred to in criteria III and IV but is included here as a summary of the data discussed above.

TABLE II

I	II	III	IV	V	VI			
Location	Estimated time of fallout (hours)	Best estimate of whole-body gamma dose (roentgens)	Skin effects	Personnel reading	Best estimate of average dose rates (mr./hr.) of the islands (taken at 3 feet above the ground) and of natives (personnel readings) after removal from radiation field, both at approximately same time			
					Island	Personnel	Ratio	Approximate time
Rongelap	5½	170	Lesions: 6 none. 19 slight. 22 moderate. 17 severe. Epilation: 28 none. 11 slight. 11 moderate. 14 severe.	(a) Majority: 80–100 mr./hr. at H+54 hours.[1] (b) Average: 60 mr./hr. at H+50 hours. Corrected average: 80 mr./hr.[2]	1300	80	16/1	H+50 hours.
Ailinginae	5½	75	Lesions: 2 none. 14 slight (very superficial). Epilation: 15 none. 3 moderate.	Average: 40 mr./hr. at H+52 hours. Corrected average: 53 mr./hr.[3]	410	53	8/1	H+52 hours.
Utirik	16–18	15	Lesions: None. Epilation: None.	Average: 20 mr./hr. Assumed: 15 mr./hr. at H+78.[4]	110	15	7/1	H+78 hours.

[1] 16 natives evacuated by air to Kwajalein and monitored upon arrival.

[2] 48 natives evacuated by U. S. S. *Philip* and monitored aboard the ship. Data suggest meter readings low by about 50 percent since natives from same island read 80 to 100 mr./hr. at Kwajalein some 4 hours later with calibrated meters.

[3] 40 mr./hr. correcte l to 60 mr./hr. according to information in footnote 2. Report did not indicate range of values among individuals nor at different parts of body.

[4] Readings taken by monitors from the *Renshaw* on the Utirik beach where there may have been some contribution to dose rates from land. After wading to ship, average personnel readings were 7 mr./hr.

Data on animal exposures.—The data on animal exposures are less firm than those for humans. Unmistakable beta burns occurred on cattle at Alamogordo in July 1945, on cattle at the Nevada Proving Grounds in spring 1952, and on horses in spring 1953. (The skin damage observed on sheep in the spring 1953 was not established to be beta burns.) However, the exact positions of the animals in relation to known amounts of fallout are not clear.

Following the last detonation of the spring 1952 series at the Nevada Proving Grounds, about one-half of a herd of 150 head of cattle were found to have evidence of beta burns. They were thought to have been 15 to 20 miles from ground zero in Kawich Valley to the northeast and to have been exposed to fallout from the last detonation. Highest dose rate readings taken along a dirt road running lengthwise through this valley integrated to 75 to 100 infinity gamma doses.

During Upshot-Knothole, 16 horses showed skin lesions over the back, and eye damage was noted in a few. The best evidence indicated that the horses were some 10 to 12 miles to the east of ground zero on March 17, 1954, where the fallout occurred from the first detonation (about 15 KT on a 300-foot tower). Radiation levels in this area are not known with certainty, but the fallout occurred in a narrow band and was carried by relatively high velocity winds so that it probably fell on the horses at a time less than 1 hour. If so, probably more than one-half of the infinity dose was delivered during the next day.

Addendum

Since the original discussion above was written, further consideration has been given to the work of Strandgvist and others [13] on the effect of fractionation of doses delivered to the skin and the onset of the observed results. It will be recalled (p. 10) that X-ray doses to the skin were fractionated in equal daily amounts, and the biological effects compared to a one-treatment dose. A log-log plot of total doses versus days after initial treatment yields straight lines.

Basically, this means that as doses are being delivered to the skin a certain rate of repair is taking place. The overall effect might be that higher initial doses from fallout material might be allowed than if one were to integrate the dose over a period of time without consideration for the repair. Because of the difference in shapes of the total beta dose curves for varying times of initial fallout versus Strandgvist X-ray curves the difference between the two curves cannot be expressed as a simple relationship.

Strandgvist quotes a 1,000 roentgen dose in 1 treatment to produce erythema using X-rays (a somewhat smaller number than other data quoted above), 1,250 roentgens if divided into 2 equal daily doses, 1,450 roentgens if divided into 3 equal daily doses, etc. Of course, there are differences between these X-ray doses and beta doses from fallout material, such as differences in doses at increasing depth of tissue and the fact that the X-rays were delivered essentially as an instantaneous dose at intervals of a day while the beta dose rates are assumed to follow the $t^{-1.2}$. However, accepting the assumptions of biological equivalence of these roentgen and beta doses and $t^{-1.2}$, one may then ask the question, "What will the beta dose rates at varying times after detonation that the contamination occurs such that the integrated doses to the skin will at no time equal Strandgvist curve for erythema?"

For early fallout times the limiting factor will be to keep the first day's beta dose below 1,250 reps; for later times of initial fallout the first day dose may be less than 1,250 reps but subsequent accumulative doses may be greater than Strandgvist curve. A family of curves was prepared of beta dose rates versus time after contamination such that each would meet but not exceed Strandgvist curve for erythema for times out to 40 days, then, based on the discussion contained under Criteria I, a conversion factor of 125 was selected to convert beta dose rates at a depth of 7 mg./cm.^{2} of tissue to gamma dose rates at 3 feet above an infinite plane. These gamma dose rates are plotted in appendix C (a).

If one accepts all the assumptions that go into preparing this curve, then one does not have to estimate the variable of how long the fallout material was in contact with the skin, for the curve suggests that as long as the initial indicated gamma dose rates are not reached, then erythema might not be expected to appear. (However, this approach still does not give assurance that *single* hot particles will not produce erythema.)

Generally, the gamma dose rate readings in the curve (appendix C (a)) suggest theoretical maximum infinite gamma doses of about 20 roentgens for a 1-hour fallout, to about 55 roentgens for a 2-day fallout. For those early times after detonation when relatively heavier fallout might be anticipated, this in-

[13] Sievert, Rolf M. The Tolerance Dose and the Prevention of Injuries Caused by Ionizing Radiations. British Journal of Radiology. Vol. XX, No. 236, August 1947.

finity gamma dose is 2 to 3 times greater than the 10 roentgens which was used as a basis of developing criteria II. However, there are two further considerations: One, the interpretation of the data, and certainly the assumptions made in developing the curve in appendix C (a) are open to discussion. Two, if one accepts the interpretations and assumptions it means a safety factor of 2 to 3—not an unreasonable quantity.

Operational feasibility.—Under the criteria recommended in criteria II, there would have been two occasions in the past where personnel would have been requested to remain indoors. Once was at Lincoln mine following the second detonation of Upshot-Knothole where they were so requested to remain indoors for 2 hours and the other occasion would have been at Riverside Cabins (population about 15) following the ninth detonation of the same series. The dose rate reading at Lincoln mine was 580 mr. per hour at H+2. In the case of Riverside Cabins, however, the radiological conditions were not ascertained until after the fallout had occurred. The maximum infinity gamma dose in the latter case was 12 to 15 roentgens.

Personnel were requested to remain indoors (for about 2 hours) following the ninth detonation of Upshot-Knothole. The highest dose rate reading was 320 mr. per hour at H+4.5 hours. This is less than the current recommendations.

CRITERIA III. DECONTAMINATION OF PERSONNEL

Where it is not possible to monitor personnel outside of a general radiation field, it is recommended that an estimate be made of the degree of personnel contamination by determining the location of the individual at the time of fallout. In the event there is uncertainty as to the validity of such an estimate, the assumption will be made that the individual was out-of-doors. In those areas where the infinity gamma dose equals or exceeds 10 roentgens, it is recommended that the individual be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field where personnel contamination exists over relatively large areas of the exposed body (one-half square foot or more):

> When the reading of a survey instrument held with the center of the probe or center of the ionization chamber 4 inches from the center of the contaminated area equals or exceeds the values given in graph III, it is recommended that personnel shall be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field, where personnel contamination exists over relatively small areas of the exposed body (less than one-half a square foot):

> The recommended maximum values shall be one-half those given in graph III. Monitoring of the head, arms, hands, lower legs, and feet will be considered as coming under this category. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated unless the radiation levels exceeds those stated below concerning monitoring of exterior surfaces of clothing.

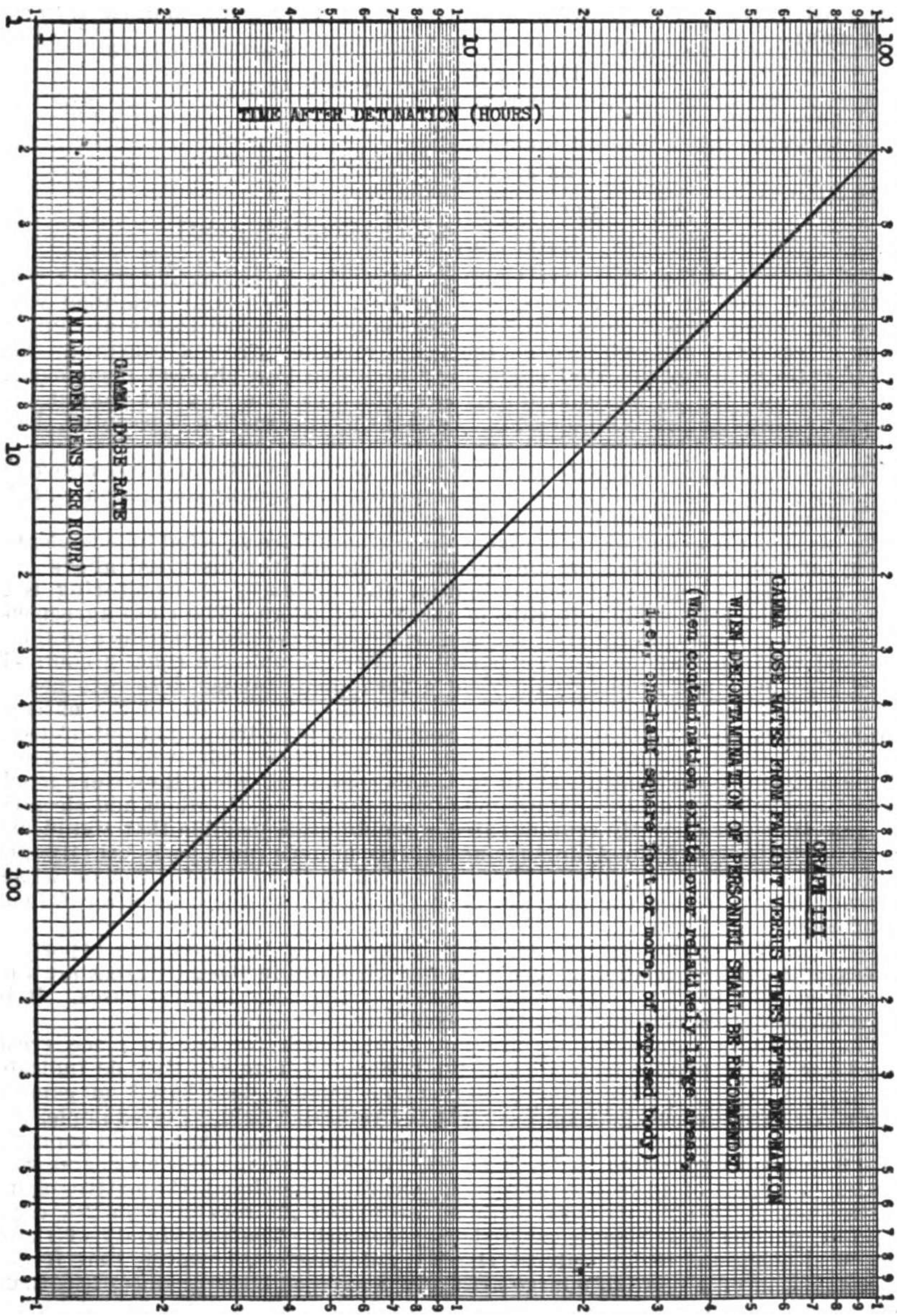
For personnel being monitored outside the general radiation field, and the contamination exists over only spots of exposed body (about the size of a half dollar or less):

> The recommended maximum values shall be one-fifth those given in graph III. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated unless the radiation levels exceed those stated below concerning monitoring of exterior surfaces of clothing.

For personnel being monitored outside the general radiation field and the contamination exists over any size area on the exterior surface only of the clothing:

> The recommended values under these conditions will be twice those given in graph III. The first recommended action shall be to resort to such simple acts as brushing off the clothing. If this action does not reduce the radiation levels to twice those given in graph III or less, then personnel shall be advised to change clothing and to bathe.

When the general contamination of a community of the degree to produce an estimated maximum theoretical infinity gamma dose of 20 roentgens or greater, personnel who have been out-of-doors at any time during the first 2 days and generally moving around in the area (as opposed to such an act as walking only between a building and a vehicle) shall be advised to brush off the footwear (outdoors), to bathe, and to change clothing as soon as possible after the final return indoors each day. In addition, personnel who go out-of-doors for any length of time during the first 2 days after such a fallout shall be advised to wash their hands at least after the final return indoors each day, and more frequently if possible.


GRAPH III
GAMMA DOSE RATES FROM FALLOUT VERSUS TIMES AFTER DETONATION
WHEN DECONTAMINATION OF PERSONNEL SHALL BE RECOMMENDED
(When contamination exists over relatively large areas,
i.e., one-half square foot or more, of exposed body)
TIME AFTER DETONATION (HOURS)
GAMMA DOSE RATE
(MILLIROENTGENS PER HOUR)
1
10
100

Discussion

Data on humans.—In table II it was suggested that the relative average gamma dose rates from an infinity contaminated field at 3 feet above the ground compared to that on the natives measured by a survey meter held close to the body was:

$$\frac{110 \text{ mr./hr.}}{15 \text{ mr./hr.}} \cong 7/1 \text{ (Utirik Atoll)}$$

$$\frac{410 \text{ mr./hr.}}{53 \text{ mr./hr.}} \cong 8/1 \text{ (Ailinginae Atoll)}$$

$$\frac{1{,}300 \text{ mr./hr.}}{80 \text{ mr./hr.}} \cong 16/1 \text{ (Rongelap Atoll)}$$

It is recognized that there are many uncertainties in estimating such a relationship by this means. Even if one assumes the dose rate readings were taken accurately, the factors involved, especially in relation to the amount of material collected and retained on the body, certainly are not constant. The higher ratio at Rongelap Atoll might have been due to a physical phenomenon where the quantity of material falling per unit area was so great that it was not retained so completely on the body. Even if this explanation is accepted, there still remain many questions.

Theoretical considerations indicate a gamma dose rate ratio at 3 feet above an infinitely contaminated field to that at 4 inches from an equally contaminated field of 6-inch radius to be about 7/1. (See appendix D.)

The sizes of areas and distances from the surfaces were selected independently of any of the information on the fallout on the natives discussed above and were estimates of areas of contamination and distances of monitoring that appeared to be reasonable estimates of these parameters. The close agreement between the gamma dose rate ratios based on theoretical considerations and those observed with the natives is circumstantial. For example, an equally contaminated area of 3-inch radius would yield a theoretical gamma dose rate nearly 3 times less than the selected area of 6-inch radius. In the case of the natives, however, it is believed that they were seminaked, perspiring, and out-of-doors during the fallout, so that it is not unreasonable to expect relatively large areas of the body to be contaminated. In fact, this was noted when they were monitored. By their acts of walking around during the period of fallout and sleeping on mats that were heavily contaminated it would seem possible that significant areas of the bodies of the Ailinginae and Utirik natives could be as heavily contaminated as was the ground. (It is unknown if there were sufficient winds that might have raised the material from the ground to the body after fallout occurred.)

There is further uncertainty of what is meant by the monitor's report of "average" personnel readings. The dose rate readings in the hair are known to have been significantly higher than the rest of the body in most cases. It is unknown how these readings were "averaged."

Whereas these data certainly are not firm enough for one to place great confidence in the precise quantities of the ratios of 7/1 or 8/1, they do indicate the obvious fallacy of accepting a 10-roentgen infinity dose based on gamma dose rates measured on personnel outside the radiation field. For example, the natives from Ailinginae showed personnel dose rates readings that would approximate 9 roentgens (gamma) in 2¼ days, and yet skin damage to some degree was evident in 14 out of 16 of the personnel. On the other hand, the natives from Utirik showed no skin damage, with an estimated 2.2 roentgens in 2½ days based on gamma dose rates measured on personnel. The uncertainty of these data was discussed under criteria II. They do suggest, however, that if the contamination of a relatively large area of the exposed body produces less than 1 roentgen infinite gamma dose as measured by a survey meter held 4 inches from the surface there is a large probability that beta burns will not result. (See also discussion under criteria II.)

Doses from small sources.—When the same dose rate reading is produced at a given height above a surface from a smaller area, the amount of contamination per unit area is greater (other factors being equal). Therefore, it would seem desirable to reduce the recommended dose rate levels when relatively small areas are involved. It is recognized that radiation from another nearby spot may

contribute to the survey meter reading when monitoring a small area on personnel, but this has not been taken into account, first, because of the difficulty of establishing a prior appraisal of this variable factor and, second, whatever this contribution may be it will now become an added safety factor.

Of course, the problem is still complex, because when considering smaller and smaller areas the eventual end point is a single particle. An estimate of beta doses at the surface of an imaginary sphere surrounding a fallout particle is given in appendix E and an estimate of beta doses from a single particle required to produce recognizable erythema is presented in appendix F. Calculations indicate that the specific activity of some individual particles found in fallout would be great enough to produce recognizable erythema if held in contact with the skin for less than 1 day, yet the gamma dose rate reading at 4 inches may be relatively small. (See appendix G.)

Additional information on doses from individual particles has recently been reported.[14] The particles found in and around Hanford consisted principally of three radioisotopes, Ru-103, Ru-106, and its daughter Rh-106. The data and calculations in appendix H also strongly indicate that a single fallout particle could produce a recognizable erythema.

Contamination of clothing.—In the case of contamination of clothing, higher dose rates might be tolerated than those for exposed parts of the body. This was exemplified in the natives where no beta burns were observed under clothing of the most highly contaminated personnel. (This does not include such areas as under the waist line where material apparently collected and was held in place.) On the other hand, very large increases in contamination should not be tolerated since it is possible for the clothing to be rearranged so as to bring the contaminated surface in contact with the skin. Further, it is not unlikely that one may rub his hands over his clothing and then through the hair where the material could be held in place for relatively long periods of time.

Beta exposure to the hands.—A further consideration is the beta dose to the hands resulting from handling objects contaminated with fallout material. Although some data are available on beta burns from handling radioactive objects, the conditions are so different from those associated with fallout that comparisons probably would not be valid.[15]

If the above assumptions and calculations are correct concerning contamination of a general area from fallout, then the transfer of all the radioactive material to the hands from an object of equal area would not constitute a hazard. Thus, one might consider using as criteria for monitoring objects, the dose readings given above for monitoring personnel outside the general radiation field. However, the problem is more complex, since the hands may come into contact with contaminated surfaces many times larger in area than the hands, with an undetermined percentage of activity being transferred to the hands. Of course, an added uncertainty is the frequency of washing of the hands and/or the rubbing off of the material from the hands.

Further, one might speculate that a given surface could have significantly higher contamination than the general area and that the handling of such a surface could constitute a greater risk. This might be true because of the greater amount of activity transferred to the hands or because of the doses delivered during the time of actually handling the object. The uncertainty of the percentage of transfer of material has been mentioned. One uncertainty in the second case is the length of time the object would be handled.

Based on calculations in appendixes B and D, when an object is held in a hand, a rough estimate of the ratio of dose rates of beta to the basal layer of the epidermis to that of the gamma reading on a survey meter held 4 inches away from an object 2 inches in radious (outside a general radiation field) might be 5,000 to 1 (appendix I). Thus, if this object were contaminated with the same activity per unit area that would produce an infinity 10-roentgen whole-body gamma dose from general contamination of the area, it would produce about 50 mr. per hour gamma at 4 inches away at H+1 hours, and about 250 reps per hour at a depth of 7 mg./cm.^{2}. Since the palms of the hands have an approximate epidermal layer of about 40 mg./cm.^{2} the beta dose to the basal layer would be about 170

[14] HW-33068. A status report. September 15, 1954.

[15] Beta Ray Burns of Human Skin. Knowlton et al., The Journal of the American Medical Association, vol. 141, No. 4. September 24, 1949.

reps per hour. (The time of H+1 was selected to show about the highest magnitude of dose rates.) If one assumes that the decay is according to $t^{-1.2}$, then the total beta dose to the basal layer of the epidermis of the hand in the next 10 hours would be about 320 reps.

Whereas the above estimates do not indicate an alarming situation, a more serious problem may come when the contamination is just less than that where evacuation is indicated. For example, the contamination of the general area may be 5 or 6 times that used as an illustration in the preceding paragraph, without evacuation being recommended. Thus, beta dose rates from handling objects, especially in times soon after fallout, may be high enough to be a problem. A simple and expedient procedure to reduce this factor is frequent washing of the hands after handling objects that were in the fallout.

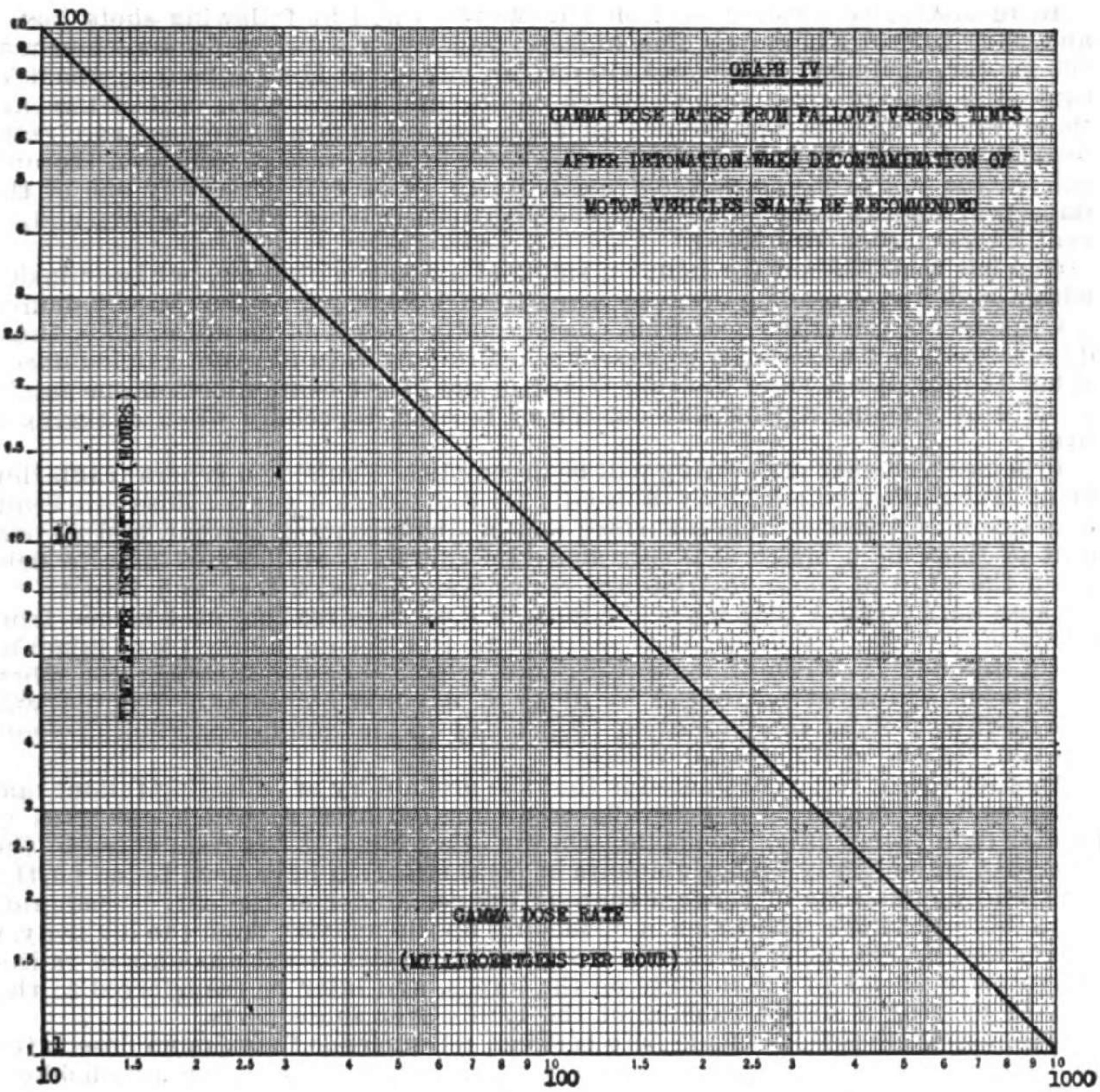
Beta exposure to the feet and lower legs.—It was suggested in criteria II that normal closed-type footwear (as compared to such as open sandals) would probably afford adequate protection against significant beta doses to the feet from fallout material on the ground. There is still the added problem if the material be scuffed up and cling to the ankles and lower legs. If there were no intervening clothing, or perhaps even with thin stockings or socks, this might result in significant biological beta doses being delivered to these parts. For example, if the gamma dose rate reading at H+3 hours were something less than 5 roentgens per hour, evacuation would not be indicated. However, for fallout material of the same concentration in contact with the skin the beta dose rate at 7 mg./cm.^{2} would be about 600 reps per hour. (See appendix B.) Presumably, personnel would be kept indoors for a few hours, but upon release the approximate beta dose rates at 7 mg./cm.^{2} would be 260 reps per hour 3 hours later, or 210 reps per hour 6 hours later. In addition, there is the variable factor of what concentration of fallout material may accumulate in the ankle region by walking around an area.

A concentration of fallout material on the ground that would result in about 20 roentgens maximum theoretical infinity gamma dose if in contact with the skin, would result in a beta dose rate to the basal layer of the skin of about 1/4 those indicated in the previous paragraph.

CRITERIA IV. MONITORING AND DECONTAMINATION OF MOTOR VEHICLES

It is recommended that when the predicted fallout across a main highway will be equivalent to a 10-roentgen infinity gamma dose or higher, vehicles be held until after the actual fallout has essentially ceased. They should be then warned to proceed with windows and air vents closed, and the cars should be monitored after passing through the contaminated area. When 5 to 10 roentgens are predicted across a main highway, vehicles should be warned to proceed with windows and air vents closed and should be monitored after passing through the contaminated area. Monitoring and warnings should be continued until there is reasonable belief that no or very few additional vehicles will exceed the values given in graph IV.

When the dose rate reading taken inside a vehicle, or taken over any exterior area that is readily accessible, equals or exceeds the values given in graph IV, the vehicle shall be cleaned inside and outside. Exterior areas to be monitored should include the wheels and under parts of the fenders but not the under carriage. The survey meter should be held approximately 4 inches from any surface.



Discussion

In the past, fallout has occurred across highways in significant quantities. Table IV–b below indicates some pertinent data during Upshot-Knothole.

TABLE IV–B

Shot No. (chronological)	Approximate yield (KT)	Tower (feet)	Time of fallout (hours)	Estimated dose rate reading of highway at time of fallout (mr./hr.)	Location	Approximate distance from ground zero (miles)
1		300	1¼	920	30 miles south of Alamo on Highway No. 93.	60
1		300	2¾	260	1 mile north of St. George, Utah.	130
6		300	5	325	Junction of U. S. Highway No. 91 and Nevada Highway No. 40.	80
7		300	4½	760	20 miles northwest Glendale, Nev., on Highway No. 93.	65
7		300	7	400	8 miles west of Mesquite, Nev., Highway No. 91.	105
9		300	2	1,000	36 miles north Glendale on Highway No. 93.	60
9		300	3¾	420	St. George, Utah, Highway No. 91.	130

Road blocks were established on Highways 93 and 91 following shots Nos. 7 and 9 of Upshot-Knothole. The highest reading on a private automobile was 100 mr./hr. (gamma) inside and 110 mr./hr. outside at H+3½ hours. About 75 cars were washed (roughly one-eighth of the total monitored). All of the cars that were washed, except the one mentioned above, had outside dose rate readings less than half of the highest. The ratio of dose rate readings on the outside of the car to inside varied from unity to about 4/1. Probably one of the important factors here is the difference between driving with windows and/or ventilators opened or closed.

One bus read 250 mr. per hour outside and average of 100 mr. per hour inside with a high inside reading over the rear seat of 140 mr. per hour at H+8¾ hours.

Considering the amount of time one normally spends in an automobile, these dose rates do not necessarily represent a health hazard in terms of gamma doses. What is probably a more limiting factor is the direct contamination one might acquire by rubbing against the outside of the car, especially when changing a tire.

It is assumed that monitoring will be accomplished outside a general radiation field. Theoretical calculations (appendix D) indicate that gamma dose rate readings taken at 4 inches from a surface will be 51 percent, 42 percent, and 27 percent of those by a meter at 3 feet above an equally contaminated infinite field when the radii of contamination are resjectively 3 feet, 2 feet, and 1 foot.

These data suggest that when the gamma dose rate reading at 4 inches from a generally contaminated car is about one-half that for an infinite plane taken at 3 feet, the degree of contamination per unit area will be about equal; and when the wheels are being monitored ½ to ¼ of a gamma dose rate reading will represent equivalent contamination (depending on the gamma contribution from the body of the contaminated vehicle).

Another factor to be considered is that the probability of collecting fallout material on the body from a generally contaminated area in which one lives is greater than from one's automobile. On the other hand, it has been noted in the past that significantly higher amounts of contamination have been found on the tires and under parts of fenders than on the remainder of the car. (Undoubtedly, this is a simple phenomenon of picking up the activity from the highway.) It one were to change a heavily contaminated tire, significant amounts of radioactive material might accumulate on the hands, and later be transferred to the hair or eyes by a simple rubbing of the hands over those parts.

A comparison might be made here between recommended maximum dose rates found on personnel and the establishing of levels of activity for automobiles. There is one obvious difference, howewver; in the first case the material is already on the person while in the second case one has to introduce the factor of probability of transfer of contamination (and to what degree) from the car to the body.

The dose rates (measured as stated) in graph IV would represent about equal contamination per unit area for a car as for an infinite plane if the car were rather uniformly contaminated. If the activity were confined, say, principally to the tires and under parts of the fenders, the dose rate readings might represent nearly twice the degree of contamination. One must weigh this condition with the probability that a tire will be changed before he activity has decreased significantly.

A given dose rate reading inside a vehicle may represent less contamination per unit area due to the contribution of gamma radiation from the exterior of the vehicle. On the other hand, contamination within a vehicle would more probably be picked up by personnel than if it were on the outside. Further, it is recognized that significantly high concentrations of radioactive fallout may accumulate in such parts as the air filters of an automobile. Again, this has to be weighted against the probability that they will be handled before the activity has decreased to low levels plus the fact that it is relatively difficult to monitor such parts on a mass basis. The uncertainties present in estimating possible hazards from vehicle contamination would not justify fine distinctions in monitoring the various parts. A thorough cleaning, inside and outside, would appear to be the best solution.

One of the obvious ways to avoid much of the problem discussed in criterion IV is to prevent vehicles entering an area during the time of fallout. This will not prevent the first vehicles passing through from picking up activity on the tires from the highway. It is believed, however, this will not constitute such a troublesome problem and past experience has indicated that the activity found

on the tires noticeably decreased after several cars had passed over the highway. Further, if vehicles are not present in the fallout it will help reduce contamination of the passengers and of the insides of the vehicles.

Operational feasibility.—In the past, the criteria used for washing cars has been 7 mr./per hour, and at a later time 20 mr./per hour (gamma), inside a vehicle. This resulted in washing about 75 cars (roughly one-eighth of the total monitored) following the seventh and ninth detonations of Upshot-Knothole. Under the recommendations given in criteria IV, the bus mentioned above, but probably none of the cars, would have been washed.

The data given in graph IV-b indicate that if these radiation levels given had been predicted before the fallout, Highways Nos. 91 and 93 would have been closed prior to the fallout from the seventh detonation and possibly Highway No. 93 for the ninth detonation.

CRITERIA V. CONTAMINATION OF WATER, AIR, AND FOODSTUFFS

In any area where the theoretical gamma infinity dose exceeds 10 roentgens, adequate sampling of the water, air, and foodstuffs should be made to ascertain the conditions of possible contamination. Based on past data, however, it is not expected that under those conditions of fallout, where the radiation levels are below those stipulated for possible evacuation, that the degree of contamination will be a health hazard. (Nor is it implied here that any level above this does constitute a serious contamination of water, air, or foodstuffs.) Therefore, it is recommended that no action be taken in regard to limiting intake except to advise the washing off of such exposed foods as leafy vegetables when that action seems desirable.

Discussion

Water.—Table VI-A lists the six locations having the highest concentrations of fission products in water sources during Upshot-Knothole, and for comparative purposes the estimated external theoretical maximum gamma infinity doses.

TABLE VI-A

Locality	Concentration (microcuries per milliliter extrapolated to 3 days after detonation)	External theoretical maximum wholebody gamma infinity dose (roentgens)
Virgin River irrigation canal, Nevada	8.7×10^{-5}	6.0
Irrigation ditch, 56 miles north of Pioche, Nev	4.5×10^{-5}	.15
Lower Pahranagat Lake, Nev	3.2×10^{-6}	2.0
Virgin River at Mesquite, Nev	2.6×10^{-6}	2.5
Bunkerville, Nev. (tap water)	1.2×10^{-6}	7.0
Crystal Springs, Nev. (tap water)	1.1×10^{-6}	.15

Due to weather and to attenuation of the gamma rays by buildings, the wholebody gamma dose estimated to have been actually delivered was probably closer to one-half of the values shown.

The maximum permissible concentration of fission products in drinking water is $5 \times 10^{-3} \mu c$/ml. extrapolated to 3 days after detonation. This is considered a safe concentration for continuous consumption.

Whereas, the monitoring of water sources is of value for documentary purposes it should be recognized that the concentrations found may vary widely within small geographical areas and even at the same location at different times (taking into account radioactive decay). Thus, confidence cannot be placed in precise values. Table VI-A suggests that even if one were to have stored up the water listed at Virgin River Irrigation Canal and subsisted entirely on this for a lifetime, the concentration would be about 58 times less than the maximum permissible amount. Normal factors of dilution by additional rainfall and/or by the influx of lesser contaminated ground water would be expected to reduce the level of activity.

Air.—Considerable effort has and is being made to evaluate hazards from airborne radioactive materials, including fission products. There are certainly many unanswered problems including the possible hazard from a single particle in

the lungs. Despite the uncertainties and as yet incomplete analysis of the inhalation hazard, the preponderance of evidence today is that the external gamma hazard from fallout is the more limiting factory of the two.[16] (However, see discussion on food contamination.)

During Upshot-Knothole quite complete data were collected of concentrations of airborne activity on about 150 occasions in some 40 different localities within 200 miles of the Nevada Proving Grounds. These included monitoring of all detonations. Histograms were made of air concentrations versus time after detonation for 30 occasions and estimates were made of doses to the lungs. These data for the five communities showing the highest air concentration are given in Table VI–B. The histogram for St. George (the highest 24-hour average concentration of fallout ever measured in a populated area) is reproduced in appendix J.

TABLE VI–B

Locality	24-hour average concentration (microcuries per cubic meter)	Dose to lungs (13 weeks) based on 20 percent deposition and 100 percent retention thereafter (mreps)[1]	Theoretical maximum whole-body gamma 13-week dose (roentgens)
St. George, Utah	1.29	130	3.5
Lincoln Mine, Nev	4.0×10^{-1}	12	1.5
Mesquite, Nev	1.7×10^{-1}	13	1.0
Groom Mine, Nev	3.4×10^{-2}	7	0.35
Pioche, Nev	2.0×10^{-2}	8	0.015

[1] The method used in estimating doses to the lungs is given in appendix K.

The criteria previously established by an Ad Hoc Jangle Feasibility Committee (Washington, D. C., July 13, 1951), for air concentrations were—

"At a point of human habitation, the activity of radioactive particles in the atmosphere, averaged over a period of 24 hours, shall be limited to 100 microcuries per cubic meter of air (corresponding approximately to a ground level gamma intensity of 30 mr. per hour).

"The 24-hour average radioactivity per cubic meter of air, due to suspended particles having diameters in the range 0 micron to 5.0 microns, shall not exceed one-hundredth of the above; nor is it desirable that any individual particle in this size range have an activity greater than 10^{-2} microcuries calculated 4 hours after the blast."

In the January 20, 1954, meeting of the ad hoc committee the basis for recommending the above air concentrations was discussed. Essentially, these criteria was selected by estimating the gamma dose that might be delivered by the passing of a radioactive cloud. Since there are better methods of estimating gamma doses and since there are uncertainties in evaluating the hazards of such transitory air concentrations as experienced from fallout, and since the preponderance of evidence from past nuclear test series indicates that the external gamma hazard is more limiting than the inhalation one, it was recommended in the January 20, 1954, meeting to strike from the record the past recommendations for maximum permissible air concentrations. It was recommended that an air monitoring program be continued for documentary purposes and for whatever value the data might have in the future when new analyses might be made in the light of additional knowledge.

A further discussion of the single particle problem may be made. In arriving at the recommendation" * * * nor is it desirable that any individual particle in this size range have activity greater than 10^{-2} microcuries calculated 4 hours after the blast" a computation was made that the average radiation dose from such a particle to a sphere one-half a millimeter in radius would be 385 reps.[17] However, the conclusions may be misleading. In the case of a single particle, relatively large doses are delivered near the particle and small doses at a greater distance. Appendix L suggests one possible estimate of this phenomenon. The

[16] Ad hoc committee meeting. Washington, D. C. Jan. 20, 1954.

[17] Minutes, Meeting of Committee to Consider the Feasibility and Conditions For A Preliminary Radiologic Safety Shot for Jangle. LASL. May 21–22, 1951.

parameters involved here are many and difficult to evaluate. For example, how long will a particle remain in one place in the lung and what dose will be delivered during that time?

It has been suggested that in the upper respiratory passage 20-micron diameter particles are the upper limit of size for deposition and that "Cilia sweep 4 to 6 cycles per second. The probability of a particle remaining within 1 millimeter zone for as much as one-half hour appears to be vanishing small. * * * Protection will also be provided by the mucus lining which is itself renewed several times an hour." Accepting the estimates above and the methods illustrated in appendixes E and F, it may be computed that about 8 reps would be delivered to the surface of an imaginary stationary sphere 1 millimeter in radius by a 20-micron particle (0.5 microcurie) in 30 minutes (appendix L). Larger doses will be delivered closer to the particle but with the relatively rapid movement of the particle, it does not appear that large doses will be delivered to a great number of cells. Multiple exposures might occur from additional particles but again this risk is difficult to evaluate.

Food.—Considerable effort is being directed toward the study of contamination of food from fallout. One element of major concern is Sr–90. It has been estimated that if one were to subsist entirely on food grown from soils containing about one-tenth to 1 microcurie per square foot of Sr–90 (1,000 pounds of calcium per acre to an average depth of 6 to 7 inches), that over a period of years there would accumulate in the human skeleton a body burden of 1 microcurie of Sr–90.[18] The highest Sr–90 activity found in soils from agricultural areas, about 100 miles from the Nevada test site, now shows a concentration of about 3.4×10^{-3} microcuries per square foot. This is a factor of 30–300 times less than the one-tenth to 1 microcurie of Sr–90 quoted above. The calcium content of soils around the Nevada test site is several times greater than the 1,000 pounds per acre used as a basis for calculations, which would materially reduce the strontium uptake.

(Although not of direct concern to the Nevada test site, it is of interest to note that soils were collected from the Marshall Islands following the fallout in early March 1954. Appendix M summarizes these data.)

A recent report strongly suggests that contamination of leaf surfaces followed by either direct consumption or intake by way of milk is a far more important pathway of intake than the soil-plant-animal cycle, at least for those times of year when plants may be in a state of growth to collect the fallout. Further analysis is being planned.

This same report raises a new problem. Based on stated assumptions, the data presented indicate relative doses of:

thyroid: tens of thousands of reps
Sr^{89-90}: 300 reps
external gamma: 40 roentgens

High radioiodine doses to the fetus and baby may be particularly important. Additional evaluation will be given this problem.

CRITERIA VI. ROUTINE RADIATION EXPOSURES

The whole-body gamma effective biological dose for off-site populations should not exceed 3.9 roentgens over a period of 1 year. This total dose may result from a single exposure or series of exposures.

If integrations of dose rate readings are used in estimating the effective biological doses, then table V may be used.

TABLE V

	Multiplication factor	Effective biological dose
Maximum theoretical radiation dose from time of fallout to 15 days later	¾	
Maximum theoretical radiation dose from 15th day to 1 year	½	
Total (best estimate of effective biological dose)		

[18] Private communication, L. A. Dean, U. S. Department of Agriculture, Beltsville, Md., April 23, 1954.

If film badges or dose meters are worn on personnel and the evidence of their use supports the view that the readings are a reasonably accurate account of the radiation dose received, then the values recorded on the film badge may be accepted with a correction factor of ¾ to account for the difference between the dose received by the film badges or dosimeters (including backscatter) and that received at the tissue depth of 5 centimeters.

CRITERIA VI. ROUTINE RADIATION EXPOSURES

Discussion

In 1953 the following recommendation was made in the report of Committee To Study Nevada Proving Ground:

"It is recommended, and found to be in conformity with the present principles of determining permissible exposure limits, that for test operation personnel the total body gamma exposure be limited to 3.9 r. in 13 weeks, and that the same figure be applied to the off-site communities with the further qualification in the latter case that this is the total figure for the year. In general, this implies a single test series in any given year."

On the basis of this recommendation and the reasoning discussed under criteria I, the criteria for estimating the whole-body gamma effective biological dose are summarized in table V. It will be noted that the biological factor included under criteria I is omitted in criteria V. In the first case we are dealing with relatively high doses that may require emergency measures with their attendant hazards. It is a situation where one wishes to estimate all pertinent factors in evaluating radiation doses even though they may not be known with preciseness, before recommending an emergency action that may produce greater problems. In the case of criteria V one is concerned with relatively lower doses during routine operations. It would be difficult to justify on the one hand the proposition that weekly doses for general populations may be integrated and taken in a single exposure without penalty and on the other hand, that a given dose received over a period of a year may be administratively reduced because of biological repair. Therefore, the biological factor is omitted.

The general effects of backscattering on measured radiation doses are fairly well established. Further, knowledge of depth (tissue)-dose curves has advanced to a quantitative state.[19] Thus, there seems to be little doubt that a film badge or dosimeter worn on the person will overestimate the gamma radiation dose delivered at a depth of 5 centimeters (assumed depth of blood-forming organs). A major factor in determining this difference is the quality of radiation under consideration. One report dealing explicitly with radiation in a fallout field suggests a factor of about ¾.

[19] Permissible Dose From External Sources of Ionizing Radiation. National Bureau of Standards Handbook 59. September 24, 1954.

Appendix A. Sample Estimation of Gamma Doses Saved by Remaining Indoors

EXAMPLE I

Assume: Time of fallout = H+3 hrs
Dose rate at H+3 = 667 mr/hr

Then: Theoretical maximum dose from time of fallout to 3 hours later ... 1.30 r
Savings by remaining indoors for 3 hours ... 0.65 r
1 year effective biological dose if personnel did not remain indoors during the 3 hours (based on same assumptions contained in section on evacuation) ... ~5.5 r
Percent of 1 year effective biological dose saved by remaining indoors for the 3 hours ... ~12

EXAMPLE II

Assume: Time of fallout = H+3 hrs
Dose rate at H+3 = 667 mr/hr

Then: Theoretical maximum dose from time of fallout to 8 hours later ... 2.30 r
Savings by remaining indoors for 8 hours ... 1.15 r
1 year effective biological dose if personnel did not remain indoors during the 8 hours (based on same assumptions contained in section on evacuation) ... ~5.5 r
Percent of 1 year effective biological dose saved by remaining indoors for the 8 hours ... ~21

Appendix B. *Calculations of Beta Dose Rate at Depth of 7 Milligrams per Square Centimeter From a Thin Extended Source*

Assume: 1.5 Mev Beta (mean energy = 0.5 Mev)
$\mu = 10$ cm²/gm

(This assumes a single mass absorption coefficient.)

$$N = No\ e^{-\mu x}$$

where
No = number of betas at surface per cm² per sec.
N = number of betas at depth x
μ = mass absorption coefficient
x = distance (depth) under consideration

$$\frac{dN}{dx} = -\mu No\ e^{-\mu x}$$

$$R = \frac{\mu No\ e^{-\mu x} E}{2}$$

where
R = dose rate at depth x
E = mean energy of betas

$$R = \frac{(10) No\ e^{-(10)(0.007)} (0.5)}{2} = 2.33\ No \text{ Mev/gm-sec.}$$

$No = 3.7 \times 10^4 C$ where: C = activity in microcuries per cm²
$R = 8.65 \times 10^4 C$ Mev/gm-sec.
$R = (1.39 \times 10^{-1})(C)$ ergs/gm-sec.
$\cong 5.4\ C$ reps/hr
or $\cong 5.0\ C$ rads/hr

Example

Assume: $C = 80 \mu c/\text{cm}^2$ (beta)
$R = 5.4\ C$ where: R = dose rate at depth 7 mg/cm² in reps
C = activity/cm² in μc

$= (5.4)(80)$
$= 432$ reps/hr
or $= 400$ rads/hr

Comparison Beta Dose Rate (Reps/hr) at 7 Mg/cm² to Gamma Dose Rate Measured in Infinite Field at 3 Feet Above the Surface

Assume: 80 $\mu c/\text{cm}^2$ (beta), equivalent to 1 megacurie/mi² (gamma)

$$\frac{432}{4.1} \cong 105$$

APPENDIX C. *Experimental Data Versus Theoretical Calculations (Appendix B) in Estimating Beta Doses*

In one relevant experiment, a thin P^{32} source was prepared by soaking a filter paper in a solution of phosphates and allowing it to dry. The surface dose rates were then measured with a surface ionization chamber.[1] Pertinent data are abstracted as follows:

Thickness of source	9.6 mg/cm²
Activity of source	77.0 μc/cm²
Surface dose rate	0.127 rep/sec 457 reps/hr
Dosage rate at depth of x centimeters	$e^{-9.5x}$

A. Theoretically:

Using the equation from Appendix B

$$R = \frac{\mu N o e^{-\mu x} E}{2} \text{ (for } P^{32}\text{)}$$

Substituting above data:

$$R = \frac{9.5 N o e^{-(9.5)(0.007)} .69}{2}$$

$$= 7.0\ C \text{ reps/hr}$$

$$\text{Let } C = 77\ \mu c/\text{cm}^2$$

$$\text{Then } R = 7.0 \times 77$$

$$= 539 \text{ reps/hr at 7 mg/cm}^2\ (P^{32})$$

B. Experimentally:

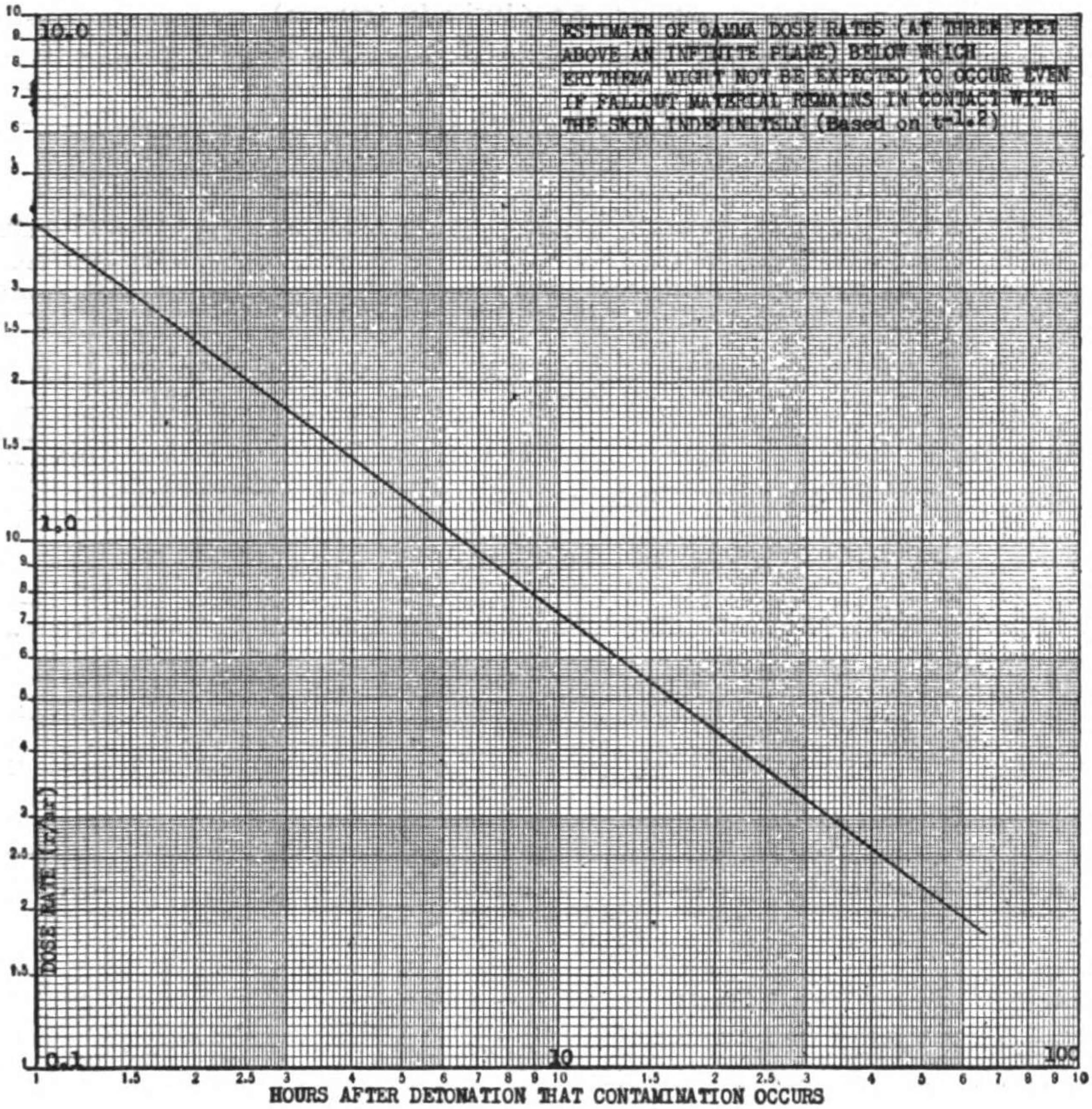
$$R = 457\ e^{-(9.5)(0.007)}$$

$$= 427 \text{ reps/hr at 7 mg/cm}^2\ (P^{32})$$

The two above approaches are within 26 percent of each other. If one extrapolates the experimental data from a source of 9.6 mg/cm² to a thin source (for comparative purposes) the two methods are within 20 percent.

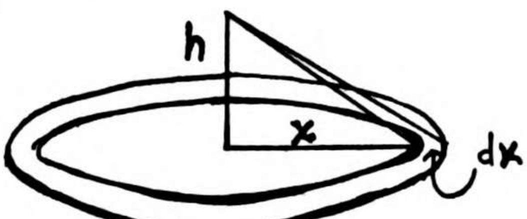
[1] *Effects of External Beta Radiation.* Zirkle, Raymond E. McGraw-Hill Book Co. 1951.

APPENDIX C (A)



APPENDIX D. *Calculations Gamma Dose Rate From a Field 6 Inches in Radius and Center of Chamber 4 Inches Above Surface*

Dose rate of gamma from a point source:



$r \cong 6CE$ where: r = r/hr
C = activity in curies per square foot
E = average energy of gammas (Mev)

$$D = 6CE\, 2\pi \int_0^x \frac{x\,dx}{h^2 + x^2},$$ where D = dose rate in r/hr

$$D = 18.8\, CE \ln \left[\frac{h^2 + x^2}{h^2}\right]$$

Example:

Let: $x = 1/2$ foot
$C = 40\mu c/cm^2$ or 3.6×10^{-2} c/ft² (gamma)
$E = 0.7$ Mev
$h = 1/3$ foot

$$D = (18.8)(3.6 \times 10^{-2})(0.7) \ln \left[\frac{(1/3)^2 + (1/2)^2}{(1/3)^2} \right]$$
$$= 0.56 \text{ r/hr}$$

Comparison Gamma Dose Rates From Infinite Plane at a Height of 3 Feet Above the Ground to Area of 6-Inch Radius and Height of 4 Inches

Assume: 1 megacurie/mile²
(3.6×10^{-2} c/ft²)

$$\frac{4.1 \text{ r/hr}}{0.56 \text{ r/hr}} = 7.3$$

APPENDIX E. *Estimate of Dose Delivered by a Single Particle of Fallout Material*

Assume: a. Point source
b. 0.5 Mev average beta energy
c. $\mu = 10$ cm²/gm
d. Rate of decay follows $t^{-1.2}$

The dose delivered at the surface of an imaginary sphere at distance R from a point source.[1]

(1)
$$K(R) = \frac{CE\mu \, e^{-\mu R}}{4\pi R^2} \frac{\text{Mev}}{\text{gram}}$$

where: $K(R)$ = dose delivered at the surface of an imaginary sphere at distance R
E = average energy of beta particles
C = total number of disintegrations
μ = mass absorption coefficient

Substituting:

$\mu = 10$ cm²/gm
$E = 0.5$ Mev

Then: (2)
$$K(R) = 0.4 \frac{e^{-10R}}{R^2} \frac{\text{Mev}}{\text{gm-disintegration}}$$

or (3.a.)
$$K(R) = 6.9 \times 10^{-6} \frac{e^{-10R}}{R^2} \frac{\text{millireps}}{\text{disintegration}}$$

or (3.b.)
$$K(R) = 6.4 \times 10^{-6} \frac{e^{-10R}}{R^2} \frac{\text{millirads}}{\text{disintegration}}$$

NOTE.—Equation (3.a.) is plotted on the attached graph.
For fission products:

(4)
$$A_a = A_1 t_a^{-1.2}$$

where: A_a = disintegrations per unit time at time "a" after detonation
A_1 = disintegrations per unit time at one unit of time after detonation

Integrating equation (2),

(5.a.)
$$C = 5A_1(t_a^{-0.2} - t_b^{-0.2})$$
and (5.b.)
$$C = 5A_a t_a^{1.2}(t_a^{-0.2} - t_b^{-0.2})$$

where: C = total number of disintegrations from time "a" to "b"
t_a = time after detonation
t_b = later time after detonation.

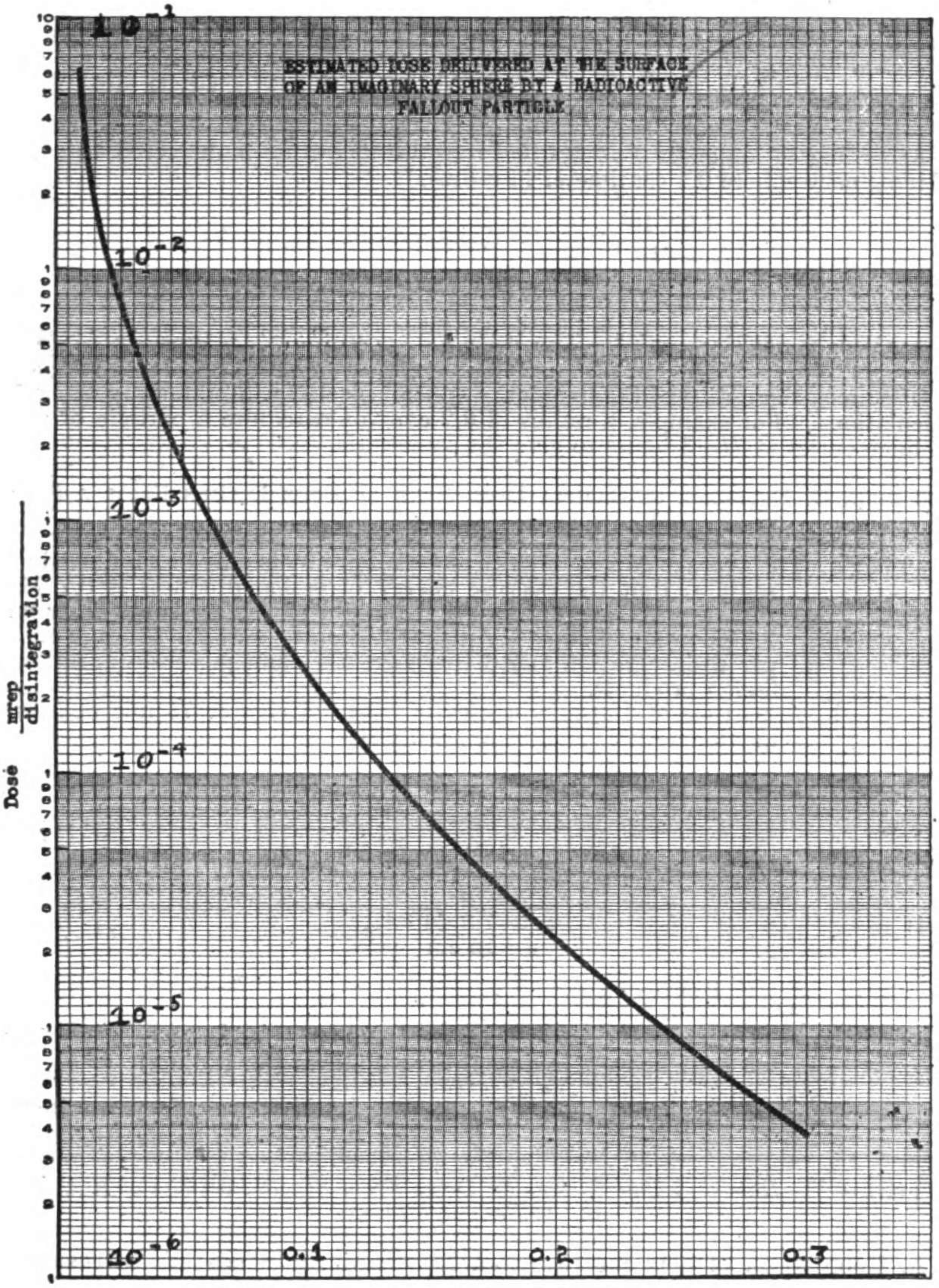
When t_b is infinite,

(6)
$$C_\infty = 5A_t t.$$

By the use of equations (3.a.) or (3.b.) and (5.b.) one may compute an estimated dose at the surface of an imaginary sphere.

Of course, the problem is the determination of "t_a" and "t_b", i. e., how long after detonation will a radioactive particle be deposited and how long will the particle remain in place. The first time (t_a) is much easier to estimate than the later (t_b).

[1] Rossi, H. H. and Ellis, R. H. "Distributed Beta Sources in Uniformly Absorbing Media.". *Nucleonics.* July 1950. V. 7 No. 1.



Radius of Imaginary Sphere in Centimeters

APPENDIX F. ESTIMATE OF BETA DOSES FROM A SINGLE PARTICLE ON THE SKIN (POSSIBLE PRODUCTION OF RECOGNIZABLE ERYTHEMA)

Let: $t_a = 3$ hours (time particle is deposited on skin)
$t_b = 27$ hours (time particle is removed)

Assume: 1500 reps = total dose required in one day to produce recognizable erythema
0.1 cm = radius of imaginary sphere within which cells must receive 2000 reps or larger.

According to appendix E, 2.5×10^{-7} reps/disintegration is delivered to surface of imaginary sphere 0.1 centimeter in radius.

$$\frac{1.5\times10^{3}}{2.5\times10^{-7}}=6\times10^{9}\text{ disintegrations required}$$
$$C=5A_a t_a^{1.2}[t_a^{-1.2}-t_b^{-0.2}]$$
$$6\times10^{9}=5A_a 3^{1.2}[3^{-0.2}-27^{-0.2}]$$
$$A_a=1.14\times10^{9}\text{ d/hr}$$
or about 8.6 μc at $H+3$ hours.

Of course, the radius of the imaginary sphere selected will materially affect the calculations. For example, a radius of 0.2 cm would require a particle of about 96 microcuries at $H+3$ hours to give the same dose.

APPENDIX G. ESTIMATE OF GAMMA DOSE RATE AT FOUR INCHES FROM A SINGLE PARTICLE OF FALLOUT MATERIAL

Assume: a. The average gamma energy of fission products may be compared with radium; that the average energy of fission products is 0.7 Mev; that the average energy from radium daughters is 0.8 Mev with 2.3 photon emissions per disintegration or that the average energy per disintegration is 2.6 times greater than per disintegration of fission products.

b. A particle of 150 microcuries of beta activity or 75 microcuries of gamma activity. (See appendix H.)

$$I=\frac{8.4\text{ mg (mc)}}{d^2}\text{ for radium through 0.5 mm of platinum.}$$

where: I = gamma dose rate (r/hr)
d = centimeters

Let: $mc = 7.5\times10^{-2}$
$d = 10$ cm

$$I=\frac{(8.4)(7.5\times10^{-2})}{10^2}$$
$$=6.3\text{ mr/hr gamma dose rate at 4 inches (for radium)}$$

$$\frac{6.3}{2.6}\cong 2.4\text{ mr/hr for fission products}$$

APPENDIX H. *Data and Calculations on Doses From Single Particles of Ruthenium and of Fallout Material*

A. Comparison of beta energies from Ru^{103} and Ru^{106} mixture to that from fission products.

Ru^{103} 0.3 Mev beta (T=42d.)
Ru^{106} ~0.03 Mev beta (T=1.0y.)
Rh^{106} 3.55 Mev beta (T=30s.)

Assume: Ru^{103}/Ru^{106} ratio of 0.75 [1]

[1] All of the basic data contained herein on ruthenium is contained in HW-33068. A status report. Sept. 15, 1954.

To estimate a mean average energy of betas from mixture:

Parts	Isotopes	Maximum energy beta	Weighted maximum energy betas
1.0	Ru^{103}	0.35	0.35
1.33	Ru^{106}	0.04	0.05
1.33	Ru^{106}	[1] 3.35	4.45
Total			4.85

[1] Average.

$$\frac{4.85}{3.66} \cong 1.3$$

Average energy ~0.43 or roughly equivalent to that assumed for fission products.

(Of course, the average energy of the betas is not the sole consideration. The spectral distribution of the betas from Rh^{106} probably is quite different from that of fission products, thus affecting the depth dose curve.)

B. Data on doses and effects from single particles of Ru^{103} and Ru^{106}:

	a	b
1. Size of particle	40 μ	120 μ.
Activity of particle	1.1 μc	11 μc.
Dose rate to 7 mg/cm²	6,600 rads/hr	27,500 rads/hr.
Time dose delivered	~6 days	~6 days.
2. Survey dose rate (mrads/hr)[1]	**Total skin dose (rads)[2]**	**Effects**
400	~500,000	None visible.
750	~900,000	Reddening.
2,500	~2,000,000	Desquamation.
11,000	~6,000,000	Tissue destruction.
21,000	~7,000,000	Tissue destruction—2 cm across. 8 mm deep.

[1] 90 mrads/hr≅1 μc.

[2] "Total dose refers to the hot spot directly below the particle, and is valid only as to order of magnitude."

C. $\frac{750}{90} \cong 8.3$ μc estimated activity of particle producing reddening effect in about 144 hours. The estimated size is 100 microns.

D. (8.3) (144) = 1200 μc total activity accounted for in the 144 hours that the dose was delivered. (Assuming constant activity during the 144 hours.)

E. What specific activity of a particle of fallout would be required to deliver the same dose in the same length of time?

The answer to this question depends upon the time after detonation that the particle comes in contact with the skin. Assuming this time to be H+3 hours, the specific activity would have to be about 150 μc for the same size particle.

Since the particle may be washed off before 6 days have expired, one may consider the problem another way. What must be the specific activity of a particle at H+3 hours to deliver this dose in the next 24 hours?

According to Strandgvist (p. 6), only about 70 percent of a 6-day dose need be delivered in one day to produce the same effect (erythema). Accepting this, then a particle with about the same activity (160 μc) at H+3 hours would be sufficient to deliver an erythema dose in 1 day.

F. The following data are reported for single particles collected during Upshot-Knothole and Tumbler-Snapper.

Size of particle (μ)	Activity extrapolated to H+3 hours (μc)	Distance from ground zero (miles)
(1)	1,000	45
(1)	200	130
1,626 x 924	900	10
919	480	11
723	350	14.7
714	400	10
555	140	14.7
387	250	14.7
234	47	14.7
115	5.2	9.5
81	3.0	14.7
20	.5	----------

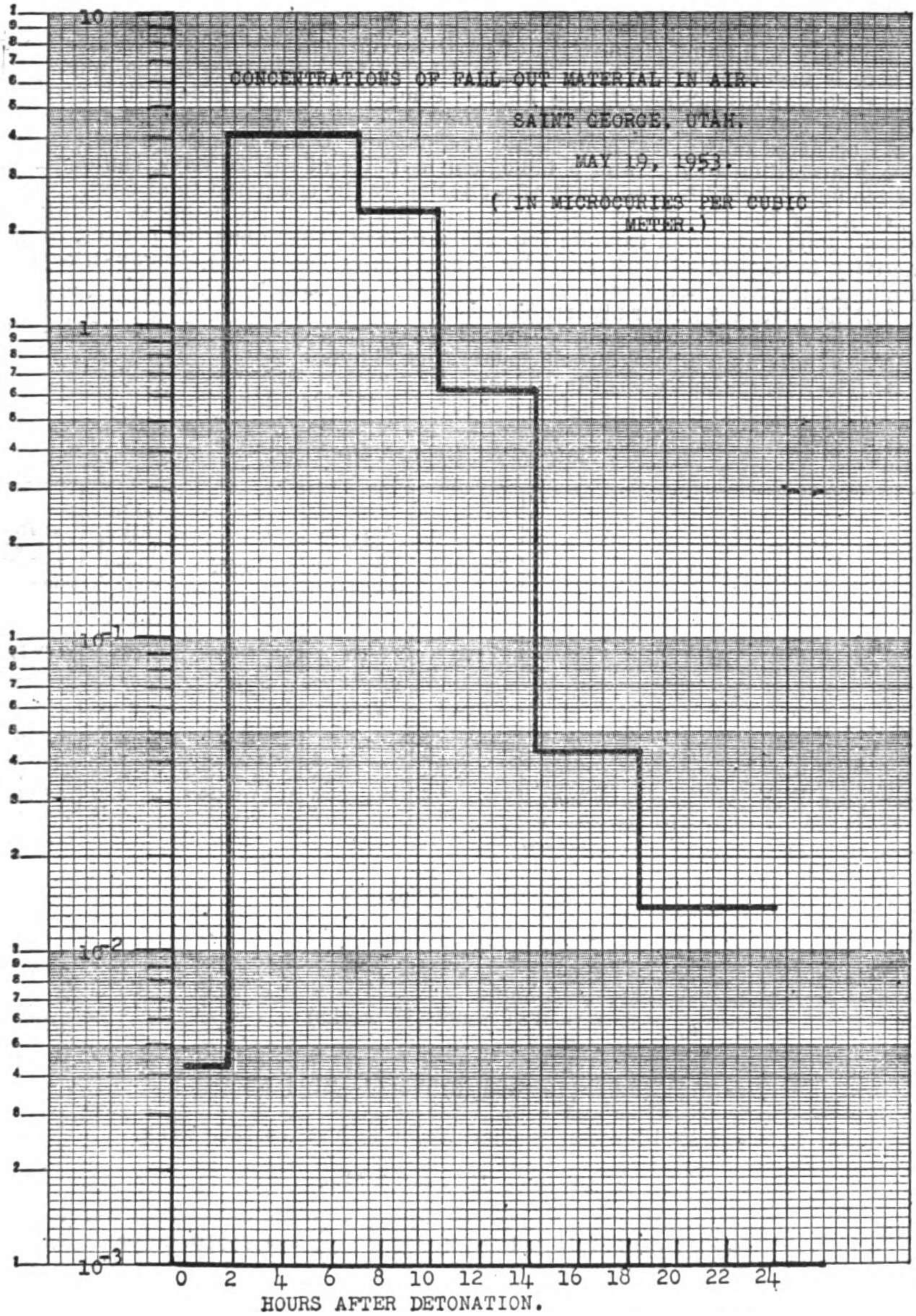
[1] Data from estimations based on radioautograph methods.

It is not intended here to imply these are the maximum specific activities per particle that existed or could exist. The data at 14.7 miles are reported to show the wide range of specific activity that may occur at one locality.

Appendix I. Estimation of Ratio of Surface Beta Dose Rate to Gamma Dose Rate at 4 Inches from an Object 2 Inches in Radius

One may assume a ratio of beta dose rate (at 7 mg/cm^2 depth of skin) to gamma dose rate (3 feet above the ground) of 125/1. If a contaminated object of say 2-inch radius were removed (or shielded) from a general radiation field the gamma dose rate at 4 inches from the surface might be some 40 times less than from an infinite plane with the same degree of contamination (appendix D), while the beta dose rate might remain almost the same value if the object is in contact with the skin. Thus, the beta-to-gamma dose rates measured under these conditions might be 5,000–1. For other than a plane surface, the gamma dose rates might be higher, thus reducing this ratio.

APPENDIX "J"


CONCENTRATIONS OF FALL OUT MATERIAL IN AIR.
SAINT GEORGE, UTAH.
MAY 19, 1953.
(IN MICROCURIES PER CUBIC METER.)
10
1
10^{-1}
10^{-2}
10^{-3}
0 2 4 6 8 10 12 14 16 18 20 22 24
HOURS AFTER DETONATION.

APPENDIX K. METHOD USED IN ESTIMATING DOSES TO THE LUNGS FROM INHALATION OF FALLOUT MATERIAL

Assumptions

The following assumptions are made in estimating radiation doses to the lungs.

A. Twenty percent of the inhaled activity is deposited.

B. There will be no elimination of particles during their radioactive lifetimes. There is uncertainty as to the biological half life of particles in the lungs. In those communities showing the highest concentrations of fallout, the peak of airborne material (which accounted for the greatest percentage of total fallout) occurred only a few hours after detonation. If one assumes a radiological decay according to $t^{-1.2}$ and a biological half life of say 30 days, the omission of biological half life would not affect seriously the computed total dose.

C. All of the activity is associated with particles in the respirable range of sizes. Past data from cascade impactors indicate that about 90 percent of the activity is associated with particles 5 microns or less in the communities surrounding the Nevada test site.

D. The lungs are uniformly irradiated.

E. The weight of the lungs is 900 grams.

F. An individual inhales 20 cubic meters per 24 hours.

G. The average beta energy is 0.5 Mev.

H. The gamma dose is negligible compared to the beta dose.

Data at St. George, Utah

(Short time) 0505	Duration	Approximate midpoint after detonation	[1]µc/M	µc Inhaled (col. II times col. IV times 0.834)	µc Retained (col. V times 0.2)
(I)	(II)	III	(IV)	(V)	(VI)
	Hours	*Hours*			
0610 to 1130	4.3	3	4.17	15.0	3.0
1130 to 1445	3.2	8	2.38	6.3	1.26
1445 to 1845	4.0	11.5	6.3×10^{-1}	2.1	0.42
1845 to 2300	4.2	15.6	4.4×10^{-2}	0.15	0.03
2300 to 0635	7.5	21.5	1.4×10^{-2}	0.09	0.02
[1] 0635 to 1835	12.0	31.5	1.4×10^{-2}	0.14	0.03

[1] Assumed.

Sample calculations

$$D=5At_a^{1.2}[t_a^{-0.2}-t_b^{-0.2}]$$

Let: $t_a=3$ hours
$t_b=2184$ hours (13 weeks)
$A=3$ µc

$$D=(5)(3\times2.22\times10^6\times60)(3)^{1.2}[3^{-0.2}-2184^{-0.2}]$$

$=4.4\times10^9$ disintegrations from 3d hour to 13th week.

Assume: $E_{avg.}=0.5$ Mev

$$(4.4\times10^9)(0.5)(1.6\times10^{-6})\left(\frac{1}{900}\right)\left(\frac{1}{39}\right)=4.2\times10^{-2}\text{ reps}$$

$$=42\text{ mreps}$$

Total lung dose for 13 weeks: ~130 mreps.

APPENDIX L. ESTIMATE OF DOSE AT SURFACE OF IMAGINARY SPHERE 1 MILLIMETER IN RADIUS

Assume: Average activity for 30 minutes is 0.5 μc at H+3 to H+3½ hours. (See reference appendix H.)

Then: $0.5\times 2.2\times 10^6\times 30=3.3\times 10^7$ disintegrations/30 minutes.

At surface of imaginary sphere 1.0 mm. in radius the dose rate from a point source is

$$2.52\times 10^{-4}\frac{\text{mreps}}{\text{disintegration}}\text{ (See appendix E.)}$$

$$(3.3\times 10^7((2.52\times 10^{-4})=8.3\times 10^3\text{ mreps/30 min.}$$
$$\cong 8\text{ reps/30 min.}$$

For particles of higher specific activity, the dose would be correspondingly higher, of course.

APPENDIX M

Estimate of Sr^{90} in soils of Pacific islands

Location	Total activity ($\mu c/ft^2$) (measured) I	Sr^{89}-Sr^{90} ($\mu c/ft^2$) (measured) II	Rough estimate external infinity gamma dose (roentgens) III
Likiep [1]	1.2×10^{-1}	8.7×10^{-3}	4
Jemo	3.0×10^{-1}	1.2×10^{-2}	4
Ailuk	1.0	3.8×10^{-2}	12
Mejuit	1.1	2.8×10^{-2}	8
Ormed	3.2×10^{-1}	1.1×10^{-2}	4
Kaven	1.6×10^{-1}	4.8×10^{-3}	2
Wotho	7.8×10^{-2}	1.3×10^{-3}	0.5
Rongelap:			
(Northern)	62.0	1.08	500
(Central)	40.0	5.5×10^{-1}	500
(1 mi. N. Village)	5.0	5.3×10^{-1}	500
(So. Cistern)	4.5	9.2×10^{-1}	500
Eriirippu [1]	230.0	12.5	4.500
Eniwetok	50.0	1.2	1,500
Kabelle	200.0	4.9	3,300
Utirik	53.0	9.8×10^{-2}	60
Bikar	3.3	4.4×10^{-1}	250
Eniwetok	8.0	6.6×10^{-1}	400
Sifo	6.1×10^{-1}	9.6×10^{-3}	170

[1] All data as of May 5, 1954, except island of Eriirippu where date is May 20, 1954.

UNITED STATES ATOMIC ENERGY COMMISSION,
Washington D. C., August 2, 1957.

Hon. CHET HOLIFIELD,
Chairman, Special Subcommittee on Radiation,
Joint Committee on Atomic Energy,
Capitol Building, Senate Post Office, Washington, D. C.

DEAR MR. HOLIFIELD: As a part of the written record of The Nature of Radioactive Fallout and Its Effects on Man, there is being reproduced a document Discussion of Radiological Safety Criteria and Procedures for Public Protection at the Nevada Test Site written by me some time ago. I would greatly appreciate it if a footnote (attached) were added to this document.

Also enclosed is a copy of the revised radiological safety criteria (April 1957) that are currently being used. I would like to suggest respectfully that these revised criteria also be printed so that the reader may have the benefit of our latest thinking on these matters.

Sincerely yours,

GORDON M. DUNNING,
Health Physicist, Division of Biology and Medicine.

Radiological Safety Criteria During Nuclear Weapons Testing at the Nevada Test Site

(April 1957)

INTRODUCTION

The criteria and procedures set forth in the following paragraphs were established after full consideration for protecting the health and welfare of the public, both in terms of radiological exposure as well as possible hazards, hardships or inconveniences resulting from disruption of normal activities. Criteria are established as guides for the Test Organization in determining whether any special actions should be taken to protect the public.

These criteria are not established with the expectation that the coming tests at the Nevada Test Site actually will result in radiation levels which will be greater than heretofore. Rather, they formalize past criteria to give even clearer guides for protecting the public. With improved methods of predicting fallout and with the use of balloons and higher towers for detonating the nuclear devices, it is expected that fallout in populated areas from future tests at the Nevada Test Site will be less than the highest amounts which have occurred in the past.

Two basic assumptions are made in this report:

(*a*) It is the responsibility of the Division of Biology and Medicine to establish such criteria for the Atomic Energy Commission as deemed necessary to protect the health and welfare of the general populace from consequences of weapons tests conducted at the Nevada Test Site.

(*b*) The operational procedures adopted for meeting these criteria shall be the responsibility of the Test Manager, as directed by the Division of Military Application, with the technical guidance of the Division of Biology and Medicine.

The following criteria do not apply to domestic or wild animals since levels of radiation which would be significant to them would have to be higher than those specified herein.

Section I. Evacuation

BACKGROUND

The decision to evacuate a community is critical for two principal reasons. One, presumably there might be a health hazard if the personnel were allowed to remain. Two, there is always an element of danger and/or hardship to personnel involved in such an emergency measure.

It is recognized that extenuating circumstances may accompany any situation where conditions indicate evacuation as a mode of action. The size of the community, areas and accommodations available for the evacuees, weather conditions, means of transportation and routes of evacuation, disposition of ambulance cases, protection of the property left behind, and many other factors may enter into the decision relative to evacuation. Further, it is recognized that under certain conditions, the evacuation of a community might prove not only rather ineffectual but could result in more radiation exposure than if the population remained in place unless the situation be adequately evaluated. A blanket evaluation cannot be made in advance; each situation can be unique. The following criteria therefore are suggested as guides in assessing the possible radiological hazards; the final decision must be made on the basis of all relevant factors known at the time. They are intended to apply principally to relatively large populations since small groups may be evacuated without equivalent potential hazards.

Owing to the necessity of making early measurements and decisions, it is to be expected that dose-rate readings, taken with survey meters, will be the available evidence at the times of concern. This necessitates making rough approximations in advance of the effects of weathering and of shielding from normal housing, in reducing the radiation exposure. The variable nature of these two parameters makes impossible the establishment of a precise rule covering all situations. Therefore, the following may be used in making conservative estimates of these effects:

(*a*) For weathering—the measured gamma dose rates at three feet above the ground be assumed to decay according to $(t)^{-1.2}$ for the first week after a detonation, $(t)^{-1.3}$ for the second week, and $(t)^{-1.4}$ thereafter.[1]

(*b*) For shielding—the accumulated dose per day be 25% less than the out-of-doors dose.[2]

In the case of a truly emergency situation where potential hazards may exist either from the fallout or from mass evacuation of large populations, it would seem proper than due consideration be given to the biological repair process that takes place with radiation doses distributed in time (recognizing that such effects from radiation as genetic changes and life shortening may not be time dependent). The estimates for biological repair for man are quite uncertain so a conservative value is used here of a half-time of repair of about four weeks.

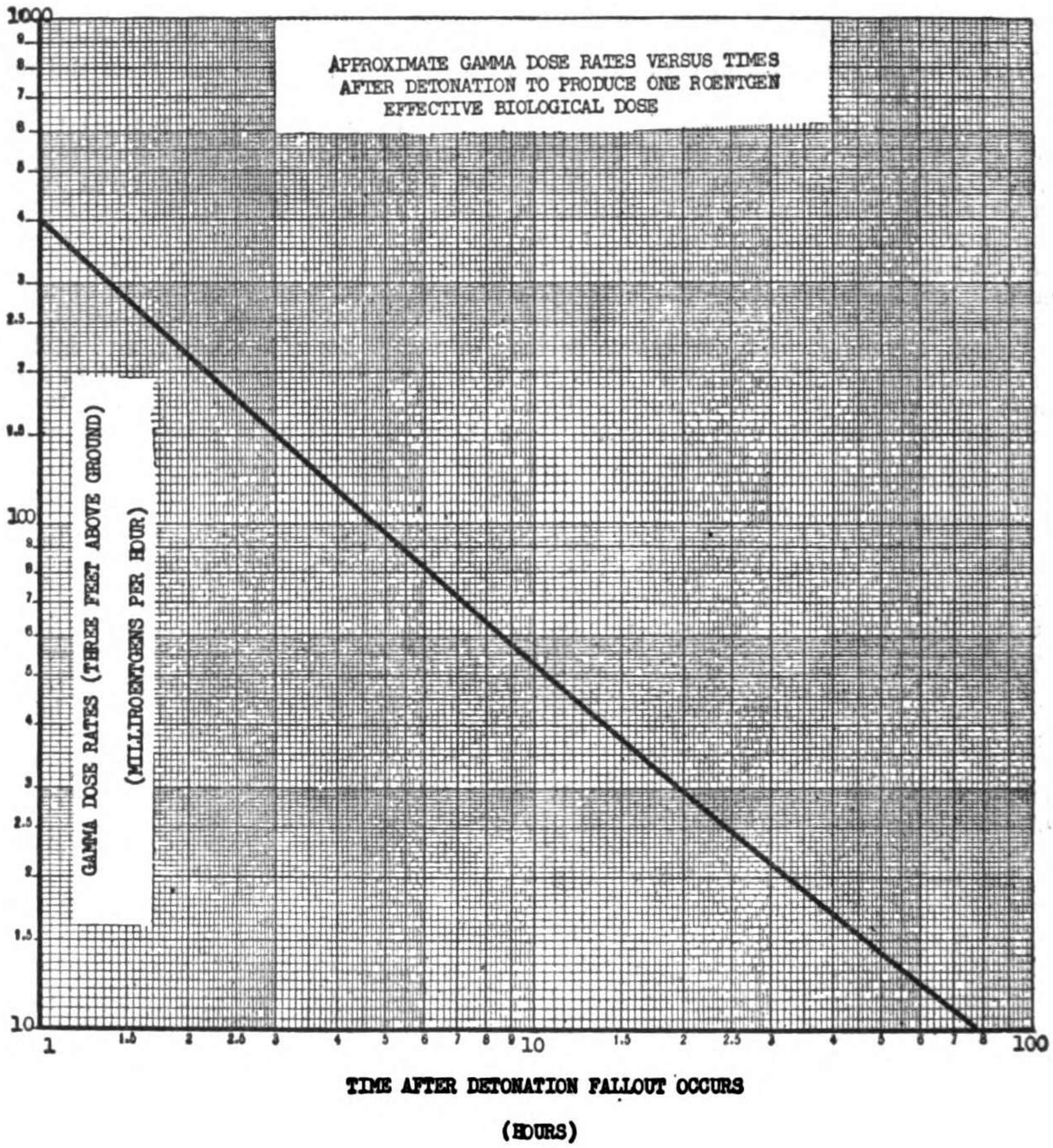
Graph I incorporates the above factors of weathering, shielding, and biological repair into a single curve. This graph may be linearly extrapolated to other dose rate readings. For example, if fallout occurs three hours after detonation and the dose rate is 10 r per hour, then about 67 r (effective biological dose) may be accumulated, i. e., $\frac{10}{0.15}\times 1.0=67$

---

[1] This concept was suggested after analyzing data from both the Nevada Test Site and the Eniwetok Proving Ground and is intended to give generalized estimates to cover a wide variety of situations. It is recognized that with the smaller fallout patterns and with the sandy soils around the Nevada Test Site, the effective decay constants may be greater than these. An expanded monitoring program will be in operation during Operation Plumbbob (1957 Series) for the collection of pertinent data to allow better estimates of effective rates and of the efforts of shielding provided by buildings.

[2] This is based on an average 12 hours per day stay in a frame house having an attenuation factor of two. It is recognized that some individuals will be in buildings having higher attenuation factors, and for longer periods of time. On the other hand, this is generally an area where people may live an appreciable amount of time out of doors and where windows and doors are left open, so the fallout material may enter the buildings. Possible revision of these estimates will await results from the expanded monitoring program during Operation Plumbbob.

GRAPH I



CRITERIA I

Effective Biological Doses may be calculated according to Graph I.

Table I may be used in evaluating the feasibility of evacuating relatively large populations.

TABLE I.—*Radiological criteria for evaluating feasibility of evacuation*

Effective biological dose:	Minimum effective biological dose that must be saved by act of evacuation (otherwise evacuation will not be indicated):
Up to 30 roentgens	(No evacuation indicated.)
30 to 50 roentgens	15 roentgens.
50 roentgens and higher	(Evacuation indicated without regard to quality of dose that might be saved, providing adequate shelters are not available and the estimated hazards concomitant with evacuation are acceptable.)

SECTION II. PERSONNEL REMAINING INDOORS

BACKGROUND

By remaining indoors (*a*) the gamma exposure will be reduced, and (*b*) there is less possibility that the fallout material will come into contact with the skin. (Beta burns have occurred in the past only when the fallout material has remained in direct contact with the skin.) To prevent or greatly reduce this latter effect, it is highly desirable to make decisions before or very shortly after the start of the fallout. Likewise, partial shielding at these early times will be of optimum benefit due to the relatively high gamma dose rates. Thus, the decisions must be based on predicted fallout in an area, or on dose-rate readings from field monitors' reports.

These predictions are of course subject to varying degrees of uncertainly so that personnel may be asked to remain indoors unnecessarily. On the other hand decisions and action must be taken relatively quickly if optimum benefits are to be derived and remaining indoors until the radiological information is more accurately evaluated probably represents one of the easiest and effective ways of meeting an emergency situation.

Due to uncertainties in our knowledge, and recognizing the usual unequal distribution of fallout, it has not been possible to establish precisely the amount of fallout in an area that could produce beta burns. The Marshallese experience showed such effects for those people exposed to 175 r and 69 r whole body gamma radiation, but none for those individuals on the Island of Utirik (370 miles from ground Zero) receiving 14 roentgens. Whether these results would hold true for other situations is not known, i. e., different particle size distribution, different type skin, etc. At one location, Riverside Cabins, Nevada, about 15 people were in an area receiving fallout in an amount equivalent to infinity dose of 15 roentgens, with no known cases of beta burns, although it is not known if anyone was out-of-doors during the time of fallout. Until more is learned of this phenomenon, it would appear advisable to remain out of the direct fallout when the amount would be such as to produce about 10 roentgens gamma infinity dose as measured at three feet above the ground. In the event personnel are out of doors during the time of this amount of fallout, the possibility of beta burns could be greatly reduced by the simple expedient of changing clothing and of bathing.

If people were not asked to remain indoors during the period of highest dose rates in an area where the infinity dose was 10 roentgens or more, their actual exposure might be in excess of 3.9 roentgens of wholebody gamma. This would not necessarily be hazardous but would exceed the established criteria for Plumbbob (Criteria VI).

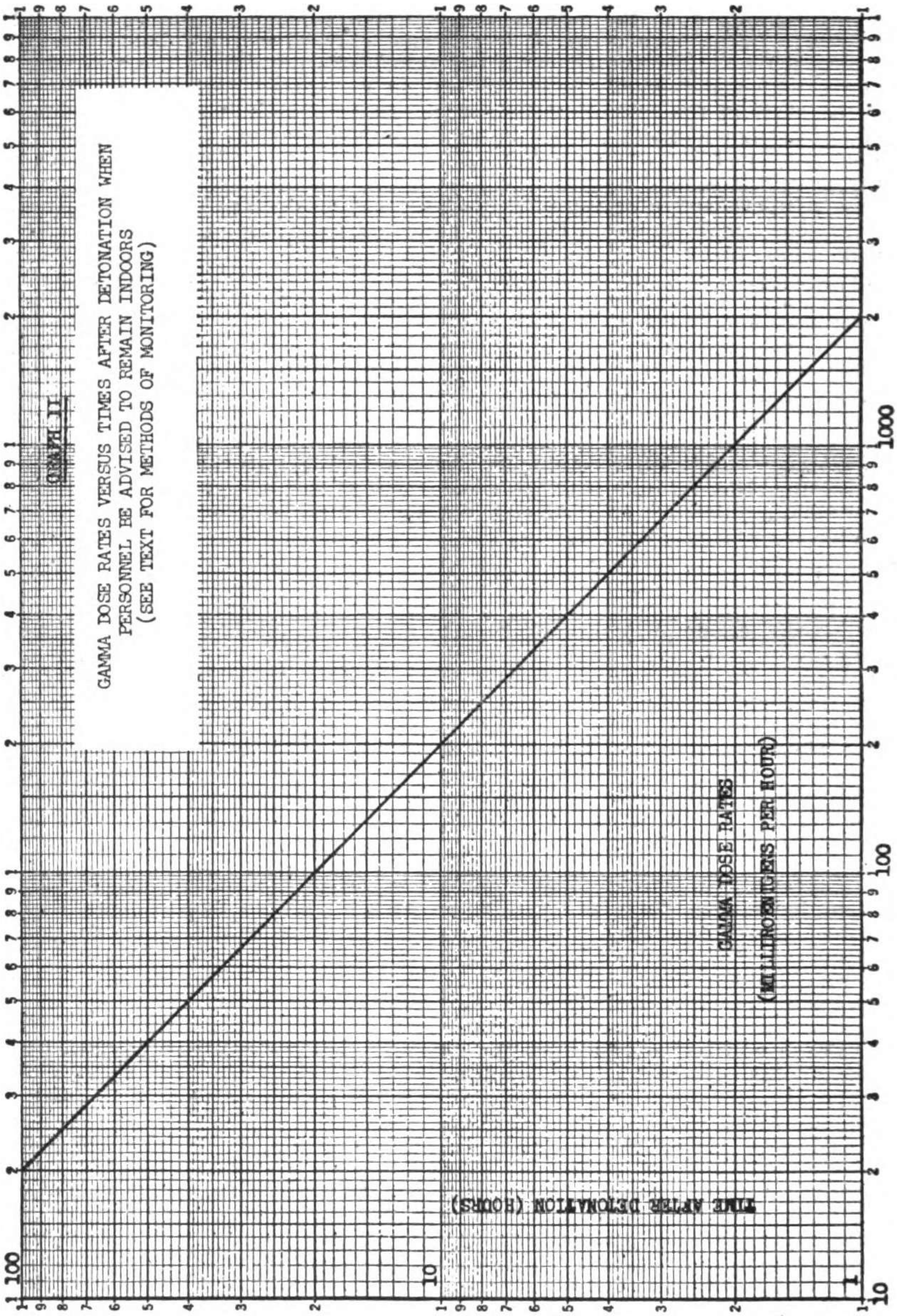
CRITERIA II

When the gamma dose rate reading as measured by a survey meter held three feet above the ground reaches the values given in Graph II at the times indicated, it is recommended that personnel be requested to remain indoors with windows and doors closed. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

In the event that there be convincing evidence that the radiation levels given in the graph will be reached, it is recommended that personnel be requested to remain indoors BEFORE fallout occurs or before the radiation levels equal those in Graph II. Release from this restrictive action should be made on the basis of further evaluation of the radiological conditions.

It is recommended that people who had been out of doors during fallout of the above magnitude or greater be advised to change clothing and to bathe. The clothing may be cleaned by normal means. While bathing, special attention should be paid to the hair and any exposed parts of the body.

In the event that the monitoring takes place AFTER the fallout has occurred, and extrapolation of the dose rate readings equals or exceeds those in Graph II at the estimated time of fallout, then it is recommended that the same advice be given as in the preceding paragraph.


GRAPH II
GAMMA DOSE RATES VERSUS TIMES AFTER DETONATION WHEN PERSONNEL BE ADVISED TO REMAIN INDOORS
(SEE TEXT FOR METHODS OF MONITORING)
GAMMA DOSE RATES
(MILLIROENTGENS PER HOUR)
TIME AFTER DETONATION (HOURS)
1000
100
10
1
10
100

SECTION III. DECONTAMINATION OF PERSONNEL

BACKGROUND

The principal purposes for decontaminating personnel are to reduce the potential beta doses to the skin, and to a lesser degree reduce the external gamma exposure. The discussion on beta doses in Section II is applicable here. In addition, there is much unknown about monitoring methods for personnel contamination. The following criteria were previously developed on the basis of measuring the gamma radiations (and then extrapolating to the accompanying beta radiations) with existing instruments. Recently new field instruments have been developed for direct beta measurement, but there remains considerably more work necessary to calibrate them in terms of beta dose rates to the body. Until this is accomplished, the past criteria may be used.

CRITERIA III

Where it is not possible to monitor personnel outside of a general radiation field, it is recommended that an estimate be made of the degree of personnel contamination by determining the location of the individual at the time of fallout. In the event there is uncertainty as to the validity of such an estimate, the assumption will be made that the individual was out-of-doors during the time of fallout. In those areas where the infinity gamma dose equals or exceeds 10 roentgens, it is recommended that the individual be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field where personnel contamination exists over relatively large areas of the EXPOSED body (one-half square foot or more):

When the reading of a survey instrument held with the center of the probe or center of the ionization chamber four inches from the center of the contaminated area, equals or exceeds the values given in Graph III it is recommended that personnel be advised to bathe and to change clothing.

For personnel being monitored outside the general radiation field, where personal contamination exists over relatively small areas of the EXPOSED body (less than one-half a square foot):

The recommended maximum values are one-half those given in Graph III. Monitoring of the head, arms, hands, lower legs, and feet will be considered as coming under this category. Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated, unless the radiation levels exceeds those stated below concerning monitoring of exterior surfaces of clothing.

For personnel being monitored outside the general radiation field, and the contamination exists over only spots of EXPOSED body (about the size of a half-dollar or less):

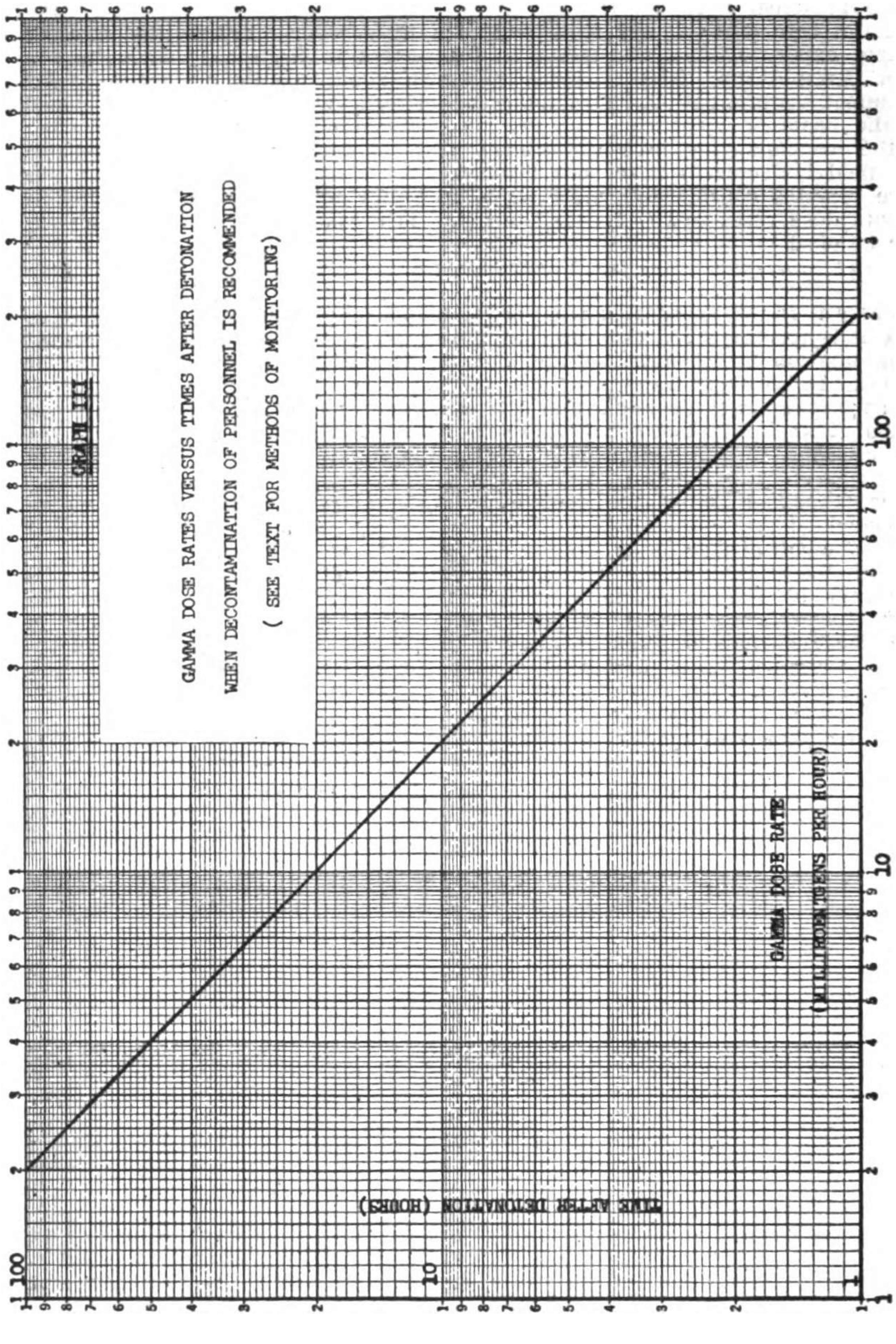
The recommended maximum values are one-fifth those given in Graph III.

Washing may be limited only to the contaminated parts, and also a change of clothing may not be indicated unless the radiation levels exceed those stated below concerning monitoring of exterior surfaces of clothing.

For personnel being monitored outside the general radiation field and the contamination exists over any size area on the exterior surface only of the clothing:

The recommended values under these conditions are twice those given in Graph III. The first recommended action shall be to resort to such simple acts as brushing off the clothing. If this action does not reduce the radiation levels to twice those given in Graph III or less, then personnel should be advised to change clothing and to bathe.

When the general contamination of a community is of the degree to produce an estimated maximum theoretical infinity gamma dose of 20 roentgens or greater, personnel who have been out-of-doors at any time during the first two days and generally moving around in the area (as apposed to such an act as walking only between a building and a vehicle) should be advised to brush off the footwear (outdoors), to bathe and to change clothing as soon as possible after the final return indoors each day. In addition personnel who go out-of-doors for any length of time during the first two days after such a fallout should be advised to wash their hands at least after the final return indoors each day, and more frequently, if possible.


GRAPH III
GAMMA DOSE RATES VERSUS TIMES AFTER DETONATION
WHEN DECONTAMINATION OF PERSONNEL IS RECOMMENDED
(SEE TEXT FOR METHODS OF MONITORING)
GAMMA DOSE RATE
(MILLIROENTGENS PER HOUR)
TIME AFTER DETONATION (HOURS)
1
10
100

SECTION IV. DECONTAMINATION OF MOTOR VEHICLES

BACKGROUND

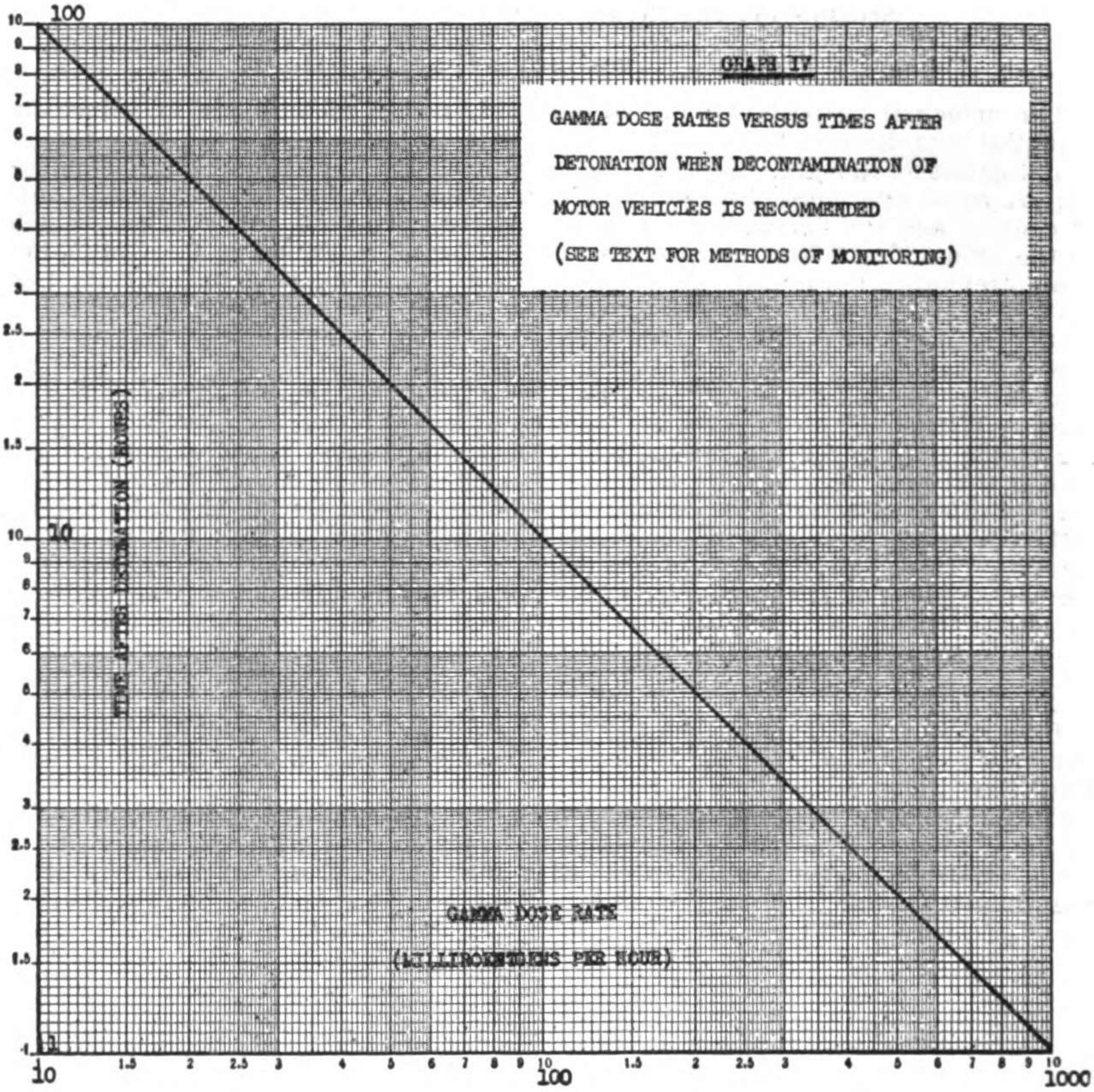
The principal purposes for decontaminating motor vehicles are to reduce the potential beta doses to the skin by contact with the vehicle, and to reduce the external gamma exposure. All of the uncertainties inherent in personnel monitoring are applicable here plus additional ones, such as estimates of the probability of contact and the amount of transfer of radioactive material from the vehicle to the skin. The following criteria for monitoring motor vehicles (Graph IV) were previously developed, and until the new beta measuring instruments (see Section III) are calibrated, will continue to be recommended.

One method of avoiding or significantly reducing vehicle contamination is to prevent their being in an area during the time of actual fallout. It is possible that fallout across a highway may be higher than that permitted for populated areas. When such a condition is predicted, it would be advisable to hold vehicular traffic until after the fallout had essentially ceased. Past experience has shown that very significantly less vehicle contamination occurs when it passes through an area afterwards compared to being present during the fallout time, although appreciable amounts can still be picked up on the tires and under the fenders. Obviously, there is not a precise value that may be given, but it is recommended that if the amount of fallout across a main highway is predicted to be in an amount equivalent to 10 roentgens or greater infinity dose, that traffic be temporarily halted until the fallout has essentially ceased.

CRITERIA IV

It is recommended that when the predicted fallout across a main highway be equivalent to 10 roentgens or greater infinity gamma dose, vehicles be held until the fallout has essentially ceased

Graph IV may be used in determining the advisability of decontaminating motor vehicles. The survey instrument should be held with the center of the probe or center of the ionization chamber four inches from any readily accessible surface.



SECTION V. CONTAMINATION OF WATER, AIR AND FOODSTUFFS

BACKGROUND

In any area where the theoretical gamma infinity dose exceeds 10 roentgens, adequate sampling of the water, air, and foodstuffs should be made to ascertain the conditions of possible contamination, if for no other reasons than as precautionary and documentary measures. Based on past data, however, it is not expected that under those conditions of fallout where the radiation levels are below those stipulated for possible evacuation, that the degree of contamination would be a health hazard. Nor is it implied here that any level above this does constitute a serious contamination of water, air, or foodstuffs. One good point of reference is the Marshallese experience where the whole-body gamma exposure was 175 roentgens yet the internal deposition from ingestion and inhalation was relatively small. In the event of a relatively heavy fallout, but less than one calling for evacuation, a common sense rule would be to wash exposed foods, such as leafy vegetables, since this is the most probable mode of intake of activity.

CRITERIA V

Monitoring of air, fod and water should be made as soon as possible in areas where the infinity dose equals or exceeds 10 roentgens. There need be no restrictive action imposed on food and water intake in areas where the fallout is less than that calling for evacuation. Washing off of such exposed foods as leafy vegetables may be advised when such action seems desirable.

Section VI. Routine Radiation Exposures

BACKGROUND

The Atomic Energy Commission has adopted, as an operational guide, 3.9 roentgens whole body external gamma radiation for off-site exposure resulting from Operation Plumbbob.

The discussion in Section I on effects of weathering and shielding on determining the actual radiation exposure is applicable here. However, the factor of biological repair is not considered for routine exposures. This factor bears on somatic effects and may justifiably be considered in emergency situations when it is necessary to weigh the relative hazards from radiation versus mass evacuation. However, for routine exposures, the actual (estimated) roentgen dose should be used. To distinguish from the Effective Biological Dose and the Infinity Dose, this exposure will be expressed as the Estimated Dose.

Graph V incorporates the assumed effects of weathering and of shielding according to the discussion in Section I. The graph may be linearly extrapolated to other dose-rate readings. For example, if fallout occurs three hours after detonation and the dose rate is 360 milli-roentgens per hour, then about three roentgens (estimated dose) may be accumulated, i. e., $\frac{360}{120}\times 1=3$.

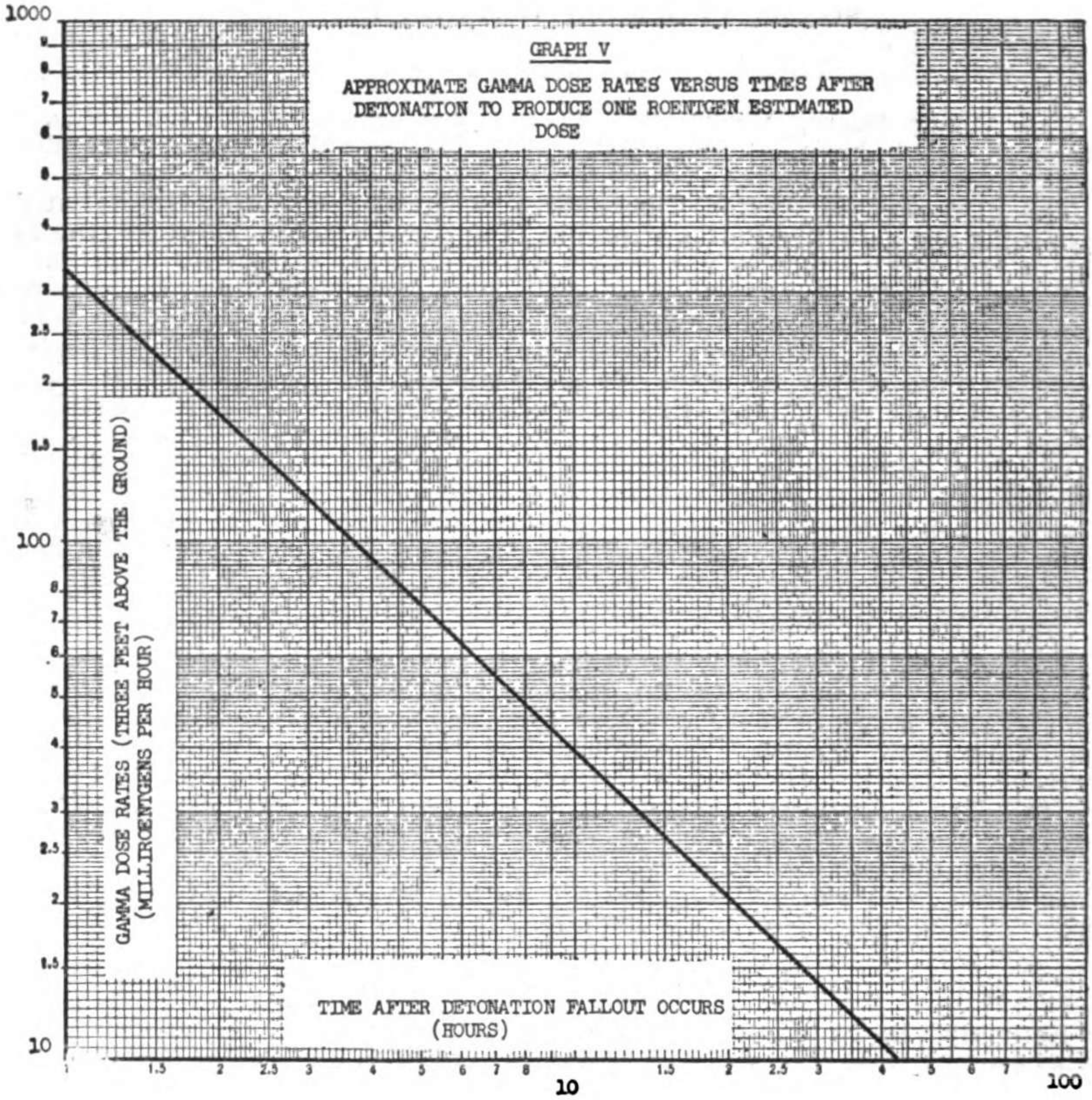
As discussed in Section I, the estimates of the effects of weathering and of shielding may be conservative for areas around the Nevada Test Site. A range of radiation doses is to be expected for these people since they will not all be living under identical conditions. The radation doses estimated by the present method is expected to fall within and toward the upper end of such a range. The information obtained from the expanded radiological monitoring program for Operation Plumbbob, should yield refinements in the method of estimating the radiation exposures.

In those cases where film badges are worn properly by personnel, the values recorded may be accepted as the Estimated Dose.

CRITERIA VI

Estimated Doses may be determined according to Graph V. In those cases where film badges are worn properly by personnel, the values recorded may be accepted as the Estimated Dose.

The whole-body gamma Estimated Dose for off-site populations should not exceed 3.9 roentgens resulting from Operation Plumbbob. This total dose may result from a single exposure or series of exposures.



Representative HOLIFIELD. This afternoon we will have Dr. Forrest Western, Division of Biology and Medicine, Atomic Energy Commission; Dr. Lyle Alexander, Department of Agriculture; and Dr. Roger Revelle, Scripps Institute of Oceanography, as witnesses.

We will meet in the Senate caucus room, room 318, at 2 p. m.

Before we recess, I have several statements to insert in the record at this point. The first is a statement of the United States Naval Radiological Defense Laboratory concerning the prediction, measurement and analysis of fallout and radiological countermeasures. Next a statement by LeRoy H. Clem, of Headquarters, Air Weather Service, United States Air Force. The third is a statement by Col. B. G. Holzman, and Col. Norair M. Lulejian, of the Air Force Research and Development Command, fourth is a statement by Dr. Donald M. Swingle, of the Army Signal Corps, Evans, South Carolina Laboratory, and finally a presentation submitted by James G. Terrill, Jr., Chief, Radiological Health Program, Public Health Service.

STATEMENT OF UNITED STATES NAVAL RADIOLOGICAL DEFENSE LABORATORY

PREDICTION OF FALLOUT

It was realized after the early weapons test operations that there existed a requirement for predicting the then little understood phenomenon of fallout. NRDL made the first studies on this subject by employing scaling techniques (1, 2, 3) similar to the approach used in the determination of blast and thermal

effects for weapons over a wide range of yields. Such scaling of radiological phenomena resulted in satisfactory results when compared to the meager experimentally determined field data (4). As more effects data became available from subsequent weapons test operations (5, 6, 7, 8) the limitations of a straightforward scaling technique were observed and the increasing dependence of the fallout on the dynamical parameters involved, such as the meteorological variables, became apparent. This led to the development of a physical model that would hopefully explain the mechanism of fallout such that given the required input parameters a knowledge of the fallout phenomenology for any type of nuclear detonation could be predicted (2, 9, 10). This model development was initiated by concentrating the effort on surface land detonations. Very little factual data were available for construction of such a model. However, it was realized that this approach offered the most positive chance of success and consequently theoretical assumptions regarding the model input parameters would have to be made. This model then defined the cloud source and associated parameters such as particle size distribution and relation of activity to particle size. A mechanism theory based on the particle settling rates and the effect of the winds aloft in determining the trajectories of these particles was established. A mathematical technique of summing the deposited activity on the earth's surface was developed such that the fallout pattern would then be established.

Because of the many initial assumptions made a great deal of effort was taken in subsequent nuclear weapons test operations to obtain refinements of these parameters by measurement (2). This work included detailed physical, chemical and radiochemical analyses of fallout particles, time dependent studies on the fallout such as time of arrival as a function of distance, rate of arrival, and time to peak activity. Activity levels as a function of distance were made (5, 6, 7). Rockets were employed to establish the radioactivity profiles within the mushroom cloud (11). Such experimental data were employed in the refinement of the physical model as well as were detailed studies of the effect of time and space variation of the winds aloft on the trajectories of the fallout particles. This data greatly improved the ability of the model to predict the fallout and continuing refinements are being made. The use of a physical model for understanding and predicting fallout appears justified (12).

A fallout forecasting technique has been developed to satisfy the immediate needs of the military. This technique employs many of the model parameters established. However it was designed for operational use and predicts only the perimeter of the fallout pattern and the radiological axis of the area or "hot line" (13, 14). It is a rapid system that was tested at Operation Redwing and proved very satisfactory for both surface land and surface water detonations. The details of this technique are described in the enclosed NRDL Technical Reports TR-127 and TR-139.

There has not been developed a satisfactory physical model for underwater or underground detonations to date. For these cases and environmental conditions other than surface or near surface burst the use of scaling techniques holds the most promise. However it is not inconceivable that the mechanism of such detonations will be understood and subsequent models developed.

The accuracy of prediction of fallout is very dependent on the quality of the meteorological data available. With precise meteorological data the area of fallout and direction of the axis of the pattern can be excellently forecast. The quantitative prediction of radiation levels at any point within the fallout area is much more difficult to predict.

It is considered essential in order to insure the application of fallout prediction technique and radiological hazard assessment to a wide variety of detonation conditions that the basic mechanisms responsible for formation of fallout, movement of fallout material in atomic clouds, its dispersal by meteorological forces and return to the earth's surface be thoroughly understood. Only a beginning to develop such an organized set of scientific data has been made.

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Measurement of Fallout

It has been the overall objective of the fallout measurements made by NRDL at the Nevada test site (3, 9, 12) and the Eniwetok Proving Grounds (1, 5, 6), to obtain those data which would allow prediction techniques to be tested and assessment methods developed for the radiological situations resulting from a wide range of nuclear detonation conditions (8).

Since fallout predictions result in the construction of gamma intensity contours, one group of measurements has featured the collection of experimental data for such contours. Direct measurement of the gamma ionization rate at a large number of points in the fallout area with a hand survey meter is the simplest and in many ways the most satisfactory method of obtaining this type of information (2, 4). When the fallout has been deposited on a solid surface, as in Nevada, surveys of this type have generally been used and further supplemented with measurements on instruments calibrated in terms of ionization of the activities of samples collected at certain locations for the primary purpose of physical, chemical, and radiochemical studies. When the fallout has been deposited on a water surface, as in the Pacific, certain other measurements are required for the interpretation of survey results. Because of the way in which the fallout material settles and disperses in the water, it has been necessary to measure its distribution to the total depth of mixing at each point of measurement before the total fallout deposited at that point could be computed. This has been accomplished in part by the use of a radiation sensitive probe which could be lowered to various depths, and in part by measuring the activities of samples collected at various depths. Both procedures have required critical instrument calibrations and theoretical work involving a number of assumptions, however, and it is probable that the results are much less accurate than those for the land surface case. In general, the measurements of this kind made by NRDL have shown that areas of the order of tens of square miles are subjected at early times to ionization intensities greater than 5 r/hr. by events in the low KT range and areas of the order of thousands of square miles to ionization intensities greater than 5 r/hr. by events in the MT range. Levels of several thousand

r/hr. at early times for both yield ranges have been measured or inferred, although less than 10 percent of the total affected area was estimated to have experienced these levels. While the probable error for contours from survey ionization rate measurements has been estimated ±20 percent for Nevada KT events, corresponding land equivalent contours for MT events in the Pacific cannot be estimated closer than within a factor of 2 or 3 at the present time.

Another group of measurements has ben directed toward obtaining time dependent data, such as the variation of the gamma field intensity and gamma energy spectrum with time and the distribution of particle sizes deposited with time at a number of locations in the fallout area (10, 12). Such information is needed both to check model theory which yields similar results and to provide a complete description of fallout phenomena. The changing gama radiation field has usually been measured by means of an instrument which recorded increments of ionization dose received at its location from all sources within unit time intervals, while gamma energy spectra have been measured on fallout samples from a known fallout area with an instrument utilizing a crystal detector, a photomultiplier and a pulse height discriminator (7, 12). NRDL results have shown that the gamma radiation field due to fallout outside the area of severe blast damage tends to build up to a maximum in approximately twice the time required for the fallout to arrive, varying from a few minutes near ground zero to 24 hours or more at distances of over 100 miles. The radioactive decay of fission products may be approximately by a straight line of slope—1.2 on a log log plot; however the more general case in which several induced activities are present, and the fission products are fractionated, leads to a complex decay curve. Spectral measurements show the average energy of the fallout gamma radiations to vary from about 0.6 Mev. at 10 hr. to 0.3 Mev. at 360 hr.

The determination of particle size distributions with time has required the development and application of specialized collectors capable of sampling automatica lly over consecutive time intervals from a few minutes to an hour or more, as well as special methods and instruments for sizing and counting the collected particles. It has been found that particles with diameters between 100 and 300 microns predominate in most collections with larger sizes (2,000–3,000 microns) increasing nearer ground zero and smaller sizes (20–100 microns) increasing farther away from ground zero. In general, data of this kind, being more direct, are more reliable for computing fraction of the bomb in the total fallout than survey results—although several sources of error such as sample bias 11 and radionuclide fractionation, do exist. On the scale utilized above, standard error in fraction calculations might be estimated at about ±25 percent for the gamma energy and emission rate method, as opposed to possibly several hundred percent by the survey method for water surfaces and less than 100 percent for land surfaces.

Extensive physical, chemical, and radiochemical analyses have been performed on the particulate produced by detonations occurring on the sandy Nevada soil and on coral atolls and the ocean surface in the Pacific. The mass of such material as well as the fraction of the bomb deposited per unit area at a number of locations has also been determined by weighing collected samples and performing radiochemical analyses. Since fallout ingestion constitutes a separate hazard from exposure to external fallout radiation, and since countermeasures and recovery procedures depend heavily on knowledge of the various properties of the contaminant, information of this kind is essential for assessment purposes.

NRDL has consistently emphasized measurements of local fallout and characterization of the phenomena associated with it. It has been possible, nevertheless, to estimate the fraction available for worldwide fallout by subtraction of the local fallout from the total produced, and this has been found to be something of the order of 50 percent for both land surface and water surface events. No closer estimate can be given because of the many uncertainties and sources of possible error in the measurements and calculations.

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ENVIRONMENTAL AEROSOL ANALYSIS

The United States Naval Radiological Defense Laboratory (USNRDL) collects and analyzes daily aerosol samples for airborne activity of air passing over the laboratory. Twenty-four-hour air samples have been collected and analyzed daily since January 1950, and is a continuing program at the laboratory. The attached graphs present a summary of the long-lived activity and half-life for these daily aerosol samples. Additional analysis on representative aerosol samples indicated this activity is due to airborne beta-gamma fission products. The appropriate dates of the various United States nuclear weapon tests are indicated.

It is observed from the graphs that in 1950 there was essentially no fission product activity in excess of 10^{-14} $\mu c/cc$. In 1951, the aerosol activity rose during the Ranger and Greenhouse operations but then dropped back to an average of 3×10^{-14} $\mu c/cc$. Successive rises and falls of the aerosol activity are noted for the succeeding years. The rises in aerosol activity, fall of 1951, 1953, 1954, 1955, and 1956 were not produced by the United States or United Kingdom nuclear weapon tests. Since December 1955, the aerosol activity has varied between 10^{-13} and 10^{-12} $\mu c/cc$. In other words, the fission product activity background was less than 10^{-14} $\mu c/cc$ in 1950, but is now around 5×10^{-13} $\mu c/cc$. The present concentration of airborne fission products is at most one-tenth of the natural radiactive aerosol (radon and thoron) concentration and is one-fifty thousandth of the industrial maximum permissible concentration for continuous exposure to undetermined mixtures of beta-gamma emitters.

NATURAL RADIOACTIVE AEROSOLS

The earth's surface atmosphere normally contains radioactive aerosols produced by the radioactive decay products of uranium and thorium minerals in the earth's crust. The amount of these natural radioactive aerosols varies from 10^{-14} $\mu c/cc.$ to 10^{-11} $\mu c/cc.$ as determined by the earth's mineral composition in a particular locale. The unit $\mu c/cc.$ (microcuries per cubic centimeter) is a measure of the amount of radioactive material per unit volume suspended in the air. 10^{-9} $\mu c/cc.$ is the present industrial maximum permissible concentration for continuous exposure to undetermined mixtures of beta-gamma emitters.

PROCEDURES

Every air sample contains natural radioactive decay products (mainly radon from the uranium series and thoron from the thorium decay series), and any other radioactive material contamination such as fission products, suspended in the air. In the analysis of the aerosol samples collected at USNRDL, the natural radioactive aerosol products, radon and thoron, are subtracted from the total aerosol activity. The daily aerosol samples are collected at USNRDL by passing 600 cubic meters of air through a 2-inch diameter high efficiency filter paper. The filter paper is then automatically counted for beta-gamma activity with a geiger tube and scaler. The minimum limit of detection on the USNRDL equipment is 10^{-14} $\mu c/cc.$

RADIOLOGICAL COUNTERMEASURES

INTRODUCTION

Most of the USNRDL concepts relative to countermeasures against nuclear attack have been previously presented in the hearings before the Subcommittee of the Committee on Government Operations. One part covering our general concepts appears in part 6 of the hearings on Civil Defense for National Survival held at San Francisco and Los Angeles on May 24, 25, 28, 29, and 31, 1956. These concepts were expanded in those portions involving the emergency periods at hearings held on H. R. 2125 at Washington, D. C., on February 5 and 6, 1957.

GENERAL CONCEPTS

The overall objective of radiological defense is to minimize the effects of nuclear attack on operations. Three time phases of defense actions are apparent: emergency phase; operational recovery phase; final recovery phase. The objectives in each phase are respectively: survival; early recovery of essential functions; ultimate recovery of normal functions. In everyday language, these objectives on a national scale are survive, stay in the war, and win the peace. There is a definite interaction between these objectives: actions which can be taken in any one phase will depend on those taken in other phases.

The general concepts on which the time phases and the respective countermeasures which apply to each phase are discussed in references 1, 2, 6, 8, 9, and 13. Our basic conclusions (reference 9) are that shelter is the central countermeasure in the emergency phase and reclamation is the central countermeasure in the operational recovery phase. The central countermeasure for the final recovery phase will probably be some form of exposure control actions; the precise nature of the actions that will be required have not as yet been taken under investigation by NRDL. In addition, reference 9 discusses other countermeasures that can be used to supplement the central countermeasures; these are called peripheral countermeasures. They include such actions as dispersal, evacuation, operational adjustments to regulate exposure to radiation.

These concepts are applicable to the case of large-scale attack with high yield thermonuclear weapons wherein all persons will be subject to effects of the attack and significantly larger areas will be subject to fallout than any other combination of effects. The concepts also apply to attack with small yield weapons in localized areas where a more limited number of people are subjected to the effects of fallout alone. People in these areas must be prepared to achieve the objectives of the defense system.

COUNTERMEASURE APPLICATIONS

Radiological countermeasures are actions that are designed to reduce, eliminate, or control exposure of personnel to radiation from radioactive material. In the emergency and operational recovery phases, the principal radiological

hazard to personnel is that from external gamma radiation. In the final recovery phase (starting several years after attack), the principal hazard is an internal one from continuous ingestion and/or inhalation of long-lived radioactive materials. Because of the long periods of possible exposure of personnel living in a radioactively contaminated environment, countermeasures must be planned as a phased, long-term, continuous, and coordinated system, Concepts and guides for planning such a system are given in references 1, 2, 8, 12, and 13. The overall system planned for a given installation or locality must be based on an analysis of the vulnerability of the target area to attack and must be independent of the condition of attack.

COUNTERMEASURE COMPONENTS

1. Shelters

The optimum requirement for the shielding afforded by a radiological shelter is a reduction in the radiation intensity of the order of 1,000 to 5,000; the use and requirements for shelters are discussed in references 1, 8, 9, 10, 13, 14, and p21. Reference 14 describes a national shelter system consisting of (*a*) simple radiological shelters, (*b*) radiological shelters with fire-storm protection in areas where fire storms could occur, and (*c*) high-performance shelters in densely populated areas to protect against high blast pressures and fire storms as well as against nuclear radiations. Many existing buildings can serve as adequate shelters; others can serve with some modifications.

2. Reclamation

The basic reclamation techniques presently available and tested are (1) manual decontamination of paved areas, building surfaces, ships, and aircraft; (2) earth-moving procedures on open land areas; and (3) automatic washdown on ships. Most of the data on decontamination are from laboratory experiments on sea-water type fallout, of which only a few of the more recent reports are referenced here. The reports that deal with the general chemistry and physics of decontamination are references 15, 16, 17, 18, 19, p4, p11, p12, and p13. Field-test and engineering-scale data are given in references 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, and p19. The application of these data to countermeasure systems planning is described in references 1 and 8.

In addition to cost of equipment, operating rates, manpower required, and radiation dose incurred, the efficiency of many of the reclamation methods depends on the physical and chemical nature of the fallout. For similar levels of radiation, fallout from detonations at sea consists mainly of sea water residues, and is most difficult to remove from surfaces; fallout from harbor detonations consists of sea water and harbor bottom soils and is more easily removed; and fallout from land detonations consists of contaminated soil particles and is easiest to remove. However, even for the latter case, decontamination of large areas is difficult and time consuming. The relative amounts removed by a method such as firehosing an asphalt road might be in the order of 30, 75, and 95 percent, for sea water harbor and land detonation fallout respectively. The amount of fallout, condition of the surface, and time of removal also influence the results. For this reason, the effectiveness of a washdown system on a ship (at sea) cannot be used as a meaure of effectiveness of a similar system on buildings (on land) without experimental verification.

Peripheral countermeasures in the operational recovery phase include (1) evacuation of nonessential persons to safe areas, (2) readjustment of operation schedules to reduce exposure times, (3) applied shielding such as sandbags around living and working areas. Whereas the presently employed concept in controlling radiation exposure is to exclude personnel from contaminated areas, the only feasible concept in radiological defense is just the reverse: the exclusion of radioactive material from clean areas.

SUMMARY OF STATE OF INFORMATION

The conceptual philosophy of an adequate radiological defense system is, at present, in a more advanced stage of development than are the supporting experimental data required for successful implementation of the system.

The main areas for which experimental data are needed are (1) shelter design and testing (habitability tests, contamination ingress, effects under fire-storm conditions, operations in shelter related to outside conditions and future operations, communications problems, and control problems); (2) operational data necessary for testing many of the planning procedures such as those given

in reference 1; (3) reclamation procedures (improve reliability of data on presently available methods, develop and test new, dry, decontamination methods to replace presently recommended methods which require large amounts of water, develop and test of automatic or low-exposure decontamination methods, improve rates and techniques of application of present methods—especially on larger areas, obtain correlations of laboratory and engineering-scale data with data from nuclear tests—most all nuclear tests are not applicable since they are intentionally detonated not to produce fallout of the kind required); (4) definition of the radiological situation and development of countermeasures therefor during the final recovery phase from data on the transport of the radioactive elements in the region of heavy fallout from the radioactive particles into plants and animals used as foodstuffs; such data are required for the planning of necessary countermeasures for a resumption of normal living conditions; and (5) a proof test of a complete proposed countermeasure system under realistic attack conditions (a test in which the complete countermeasure system with all its tested components are put together and in which the countermeasure actions are continued through all the phases); such a test cannot be made under the biased influence of a weapons-development test, since it would take 5 to 10 years to complete, not counting the preparation time.

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p9. C. F. Miller, Analysis of Fallout Data, Part IV. Fallout Patterns for Castle Shots (secret RD). (References 5 to 9 present new analytical methods, discuss reliability of data, give critique of experimental design, list types of new data required to explain the phenomenon of fallout, and give comparison between theory and experimental results.)

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p11. C. F. Miller, Theory of Decontamination of Debris From Nuclear Detonations (secret RD). (A review paper; discusses formation of fallout, reactions of fallout from detonations at sea, land, and in a harbor during contamination and decontamination processes; compares theoretical expressions with available data; and gives scaling relationships of decontamination results with yield and height (or depth of burst). References 6 through 10 used as supporting.)

p12. C. F. Miller, Generalized Decontamination Functions (secret RD). (An extension of reference 11; illustrates use of theoretical equations to interpret and extrapolate available experimental data.)

p13. C. F. Miller, Analysis of Castle Project 6.5 Data (secret RD). (An analysis of data using theory of references 11 and 12; state of knowledge on decontamination of sea-water fallout and recommendations for future improvements are discussed.)

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A Fallout Plotting Device

RESEARCH AND DEVELOPMENT TECHNICAL REPORT USNRDL–TR–127, NS 081–001, AND UNITED STATES ARMY, NOVEMBER 30, 1956

By E. A. Schuert, Physics, Technical Objective AW–7; Radiological Capabilities Branch, L. B. Werner, Head; Chemical Technology Division, E. R. Tompkins, Head; Scientific Director, P. C. Tompkins; Commanding Officer and Director, Capt. Richard S. Mandelkorn, USN, United States Naval Radiological Defense Laboratory, San Francisco, Calif.

ABSTRACT

A fallout plotting device was developed. The method requires no drafting equipment and is ideally suited for field use. At Operation Redwing it was found that untrained personnel could quickly become proficient in its employment.

SUMMARY

The problem

A plotting device is needed to speed up forecasting where fallout will fall in the field. Such a device should require no drafting equipment but still accurately plot the required data in a manner compatible with the latest fallout model theories. It should be so constructed that untrained personnel can quickly become proficient with it.

Findings

Such a device was developed and tested at Operation Redwing. It proved to be satisfactory, and suitable for field operations.

ADMINISTRATIVE INFORMATION

This work was done under Bureau of Ships project No. NS 081–001, subtask 1, technical objective AW–7. The work is described in United States Naval Radiological Defense Laboratory annual progress report to the Bureau of Ships, DD form 613, of July 1956 (enclosure (1) to commanding officer and director, USNRDL Secret letter 3–905–471 EHC: dlc serial 0014921 of August 31, 1956). The plotter was tested at Operation Redwing, project 2.6.3, as described in subtask 4B of NS 088–001 of February 1956.

The work also is part of the technical program for the Department of the Army established between Department of the Army, Office, Chief of Research and Development and Bureau of Ships (joint agreement, Nov. 23, 1955).

INTRODUCTION

This paper describes a rapid technique for plotting "particle-size"[1] and "height" lines in mapping fallout from a nuclear detonation. Since this method,

[1] Particle-size lines are often referred to as hodographs or weighted hodographs.

one of hand computation, uses a fallout plotting device that requires no dratfing equipment, it is ideally suited for field use. It was employed successfully at Operation Redwing where it was found that untrained personnel could quickly become proficient in its employment.[3]

The use of particle-size and height lines in mapping fallout is a standard technique employed in most analytical methods now in use. It simply describes a grid (fig. 1) on the earth's surface indicating where certain sizes of fallout particles, originating along a line source through the axis of symmetry of the cloud, will arrive and from what altitude they will come. These parameters are the basic data for describing the fallout pattern.

There are three requirements for determining this grid: the initial distribution of material in the atmosphere; the falling or settling rate of the material from its initial elevation; and the wind field through which the material is falling and by which it is being displaced.

The fallout plotting device computes the points of arrival on the earth's surface of a given particle size that originates at various altitudes within the mushroom cloud and its stem. Particles originating at elevations of every 5,000 feet, from the surface to 120,000 feet, are considered. In the construction of the device, account is taken of the variable speed of the settling particles due to changes in the vertical distribution of the atmosphere's density and viscosity. Aerodynamic falling equations were employed in its design. However, selection of particle falling speeds and altitude increments is arbitrary and not a fixed factor in the basic design of the plotter.

If the average wind speed and direction within a given altitude increment and the time required for a particle to fall through it are known, then the horizontal displacement of the particle can be computed for that altitude layer. Knowledge of the particle's point of arrival on the surface may be deduced from tracing a settling particle as it is displaced by each wind in each altitude increment. Plotting trajectories for each particle size at every starting elevation is the first step in determining the resultant fallout pattern; however, the drafting involved is tedious and time consuming. This effort can be reduced greatly by plotting from the ground up, as is done in the construction of a hodograph. Such a plot is made by starting at ground zero and working up through the altitude increments to the desired elevation. Although this technique does not plot the trajectory of the particle, it does define the arrival points on the surface of the earth of particles starting at each altitude increment (fig. 2).

DESCRIPTION AND USE OF DEVICE

To plot these size-lines one must make the preliminary computations of particle falling times through each altitude increment to obtain the displacement for various wind velocities. The plotter was designed with these computations built in, thereby speeding up the plotting process significantly.

The plotter consists of two parts, a base for direction or azimuth orientation and a wheel for distance or displacement. Since both of its parts are constructed of clear plastic, the plotter does not obscure the map over which it is placed. The base consists of a wind-rose having a radial line at each 10° interval on the compass. The base (fig. 3) has a narrow slot along the 180° line. If a given wind direction (in degrees from which the wind is blowing) is selected and its radial line oriented to north on the map (parallel to the north-south grids), the 180° slot becomes oriented in that direction in which a falling particle will be displaced. Thus by orienting the base of the plotter as described for any measured wind direction, the vector azimuth for the particle can be drawn through the slot of the plotter base.

The wheel (fig. 4) is pivoted at the center of the base. It has 24 equispaced radial slots. Each slot represents an altitude increment of 5,000 feet. Concentric circles intersect the radial slots to form a scale of wind speed in knots. Since the particle falling speed is a function of the atmosphere's density and viscosity and since these factors vary with altitude, the wind speed scales are so weighted

[3] A USNRDL report which will describe the detailed techniques of forecasting used at Operation Redwing and how the employment of the plotter was adapted to consider time variation of the winds is in preparation.

and the indicated length of the scale actually represents the horizontal displacement of the particle through the altitude layer of interest.

To obtain the distance the particle is displaced along its azimuth, the wheel is rotated until the proper altitude layer is alined with the 180° slot in the base and a line is plotted on the map.

It should be remembered that the weighted scales of wind speed fix the map scale, which in this case was 1 : 970,000 or 1 inch = 13.2 nautical miles. Different wind speed wheels have been constructed for several particle sizes; at present four wheels have been made.[8]

In plotting a size-line with the fallout plotter (fig. 5) one uses the same technique as one does when employing a drafting machine. However, all computations of horizontal displaced distance the particle experiences when falling through a given altitude layer are eliminated.

To plot a size-line or a trajectory, the following steps are necessary:

1. Rotate the wheel until the desired altitude increment coincides with the 180° slot in the base.
2. Place the plotter with the zero value of the wind speed scale over the given point and orient the base so that the radial line, showing the direction from which the wind blows, parallels the north-south grids of the map.
3. Draw a wind speed vector through the coincident slots.
4. Continue the process using the tip of the vector just drawn as the next point.

In constructing the prototype plotters certain specialized parameters were used in making the computations; for example, atmospheric density and viscosity were computed for a Marshall Island atmosphere, particle parameters were typical of coral fallout and special aerodynamic falling speed equations were used. Any of these variables as well as altitude increments may be so selected that a similar plotter for specialized or more general input data becomes possible. Also if one wished to assume a constant falling rate for a given size particle the wheel could be eliminated and the single wind speed scale laid out along the 180-degree slot on the base.

Figures 6A, 6B, 6C, and 7A, 7B, 7C are reproductions of the component parts of the four plotters that have been constructed. These figures can be used to construct a set of plotting devices. A reference scale has been added on each figure to relate the reduced drawings to their original size wherein the scale relationship was 1 : 970,000.

Approved by:

EUGENE P. COOPER,
Associate Scientific Director.

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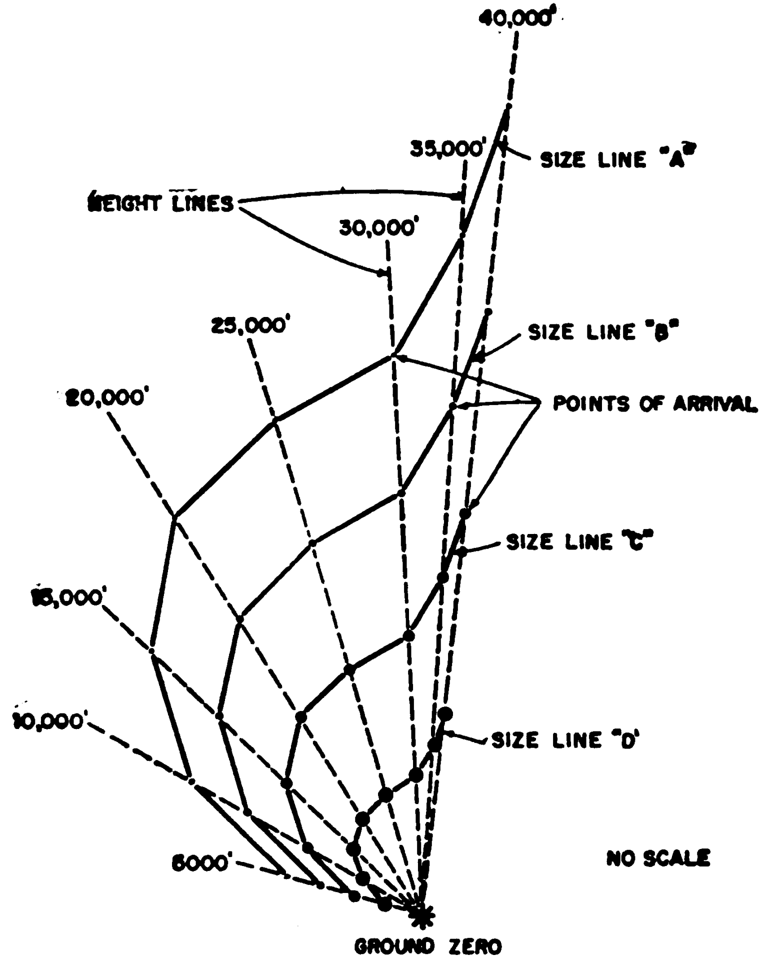
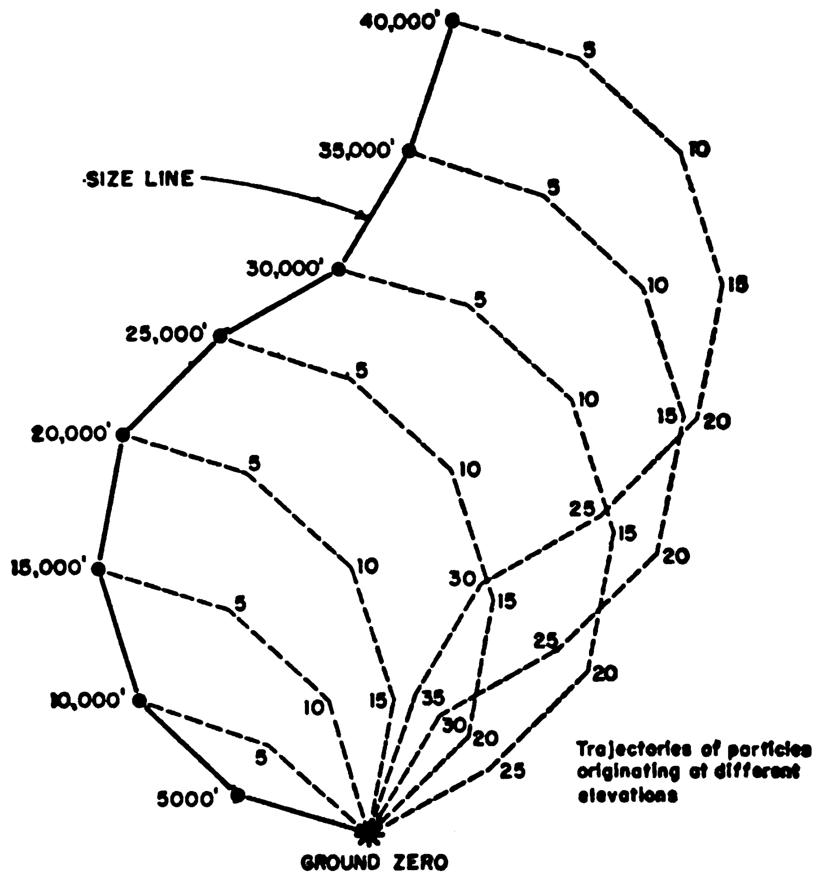
[8] These wheels are for irregular-shaped particles of density 2.36 g/cc and having diameters of 75, 100, 200, and 350μ. A plotter may be adapted for more than one particle size by adding parallel scales to each radial slot on the wheel.



NOTE: Four particle sizes originating at altitudes up to 40,000 feet in a hypothetical wind field

FIGURE 1.—Basic fallout plot showing grid of size lines and height lines.



NOTE: Particles of the same size originating at altitudes up to 40,000 feet in a hypothetical wind field

NO SCALE

FIGURE 2.—Comparison of plotting techniques either by use of trajectories or by use of a size line.

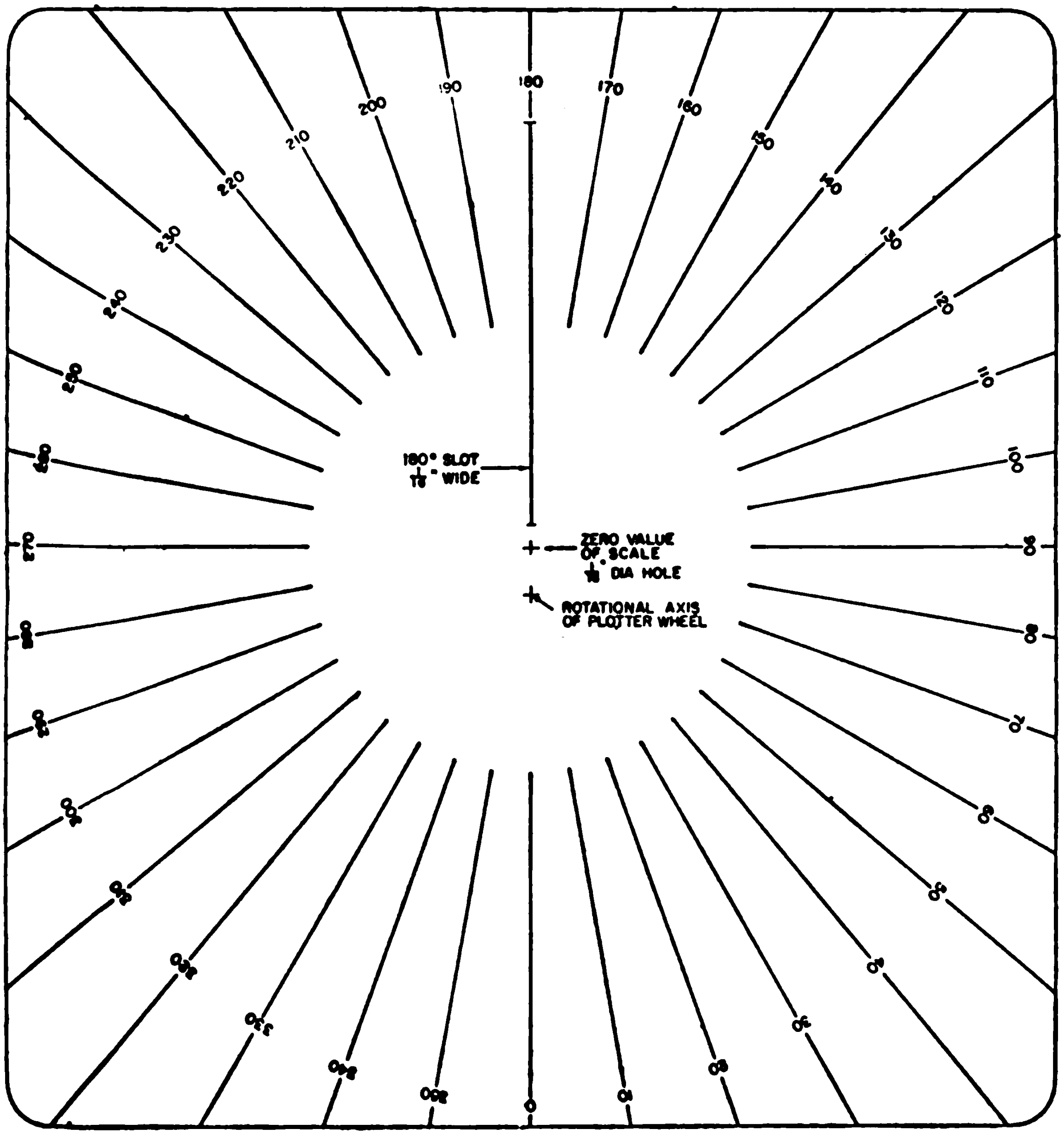


FIGURE 8.—Plotter base, for determining direction.

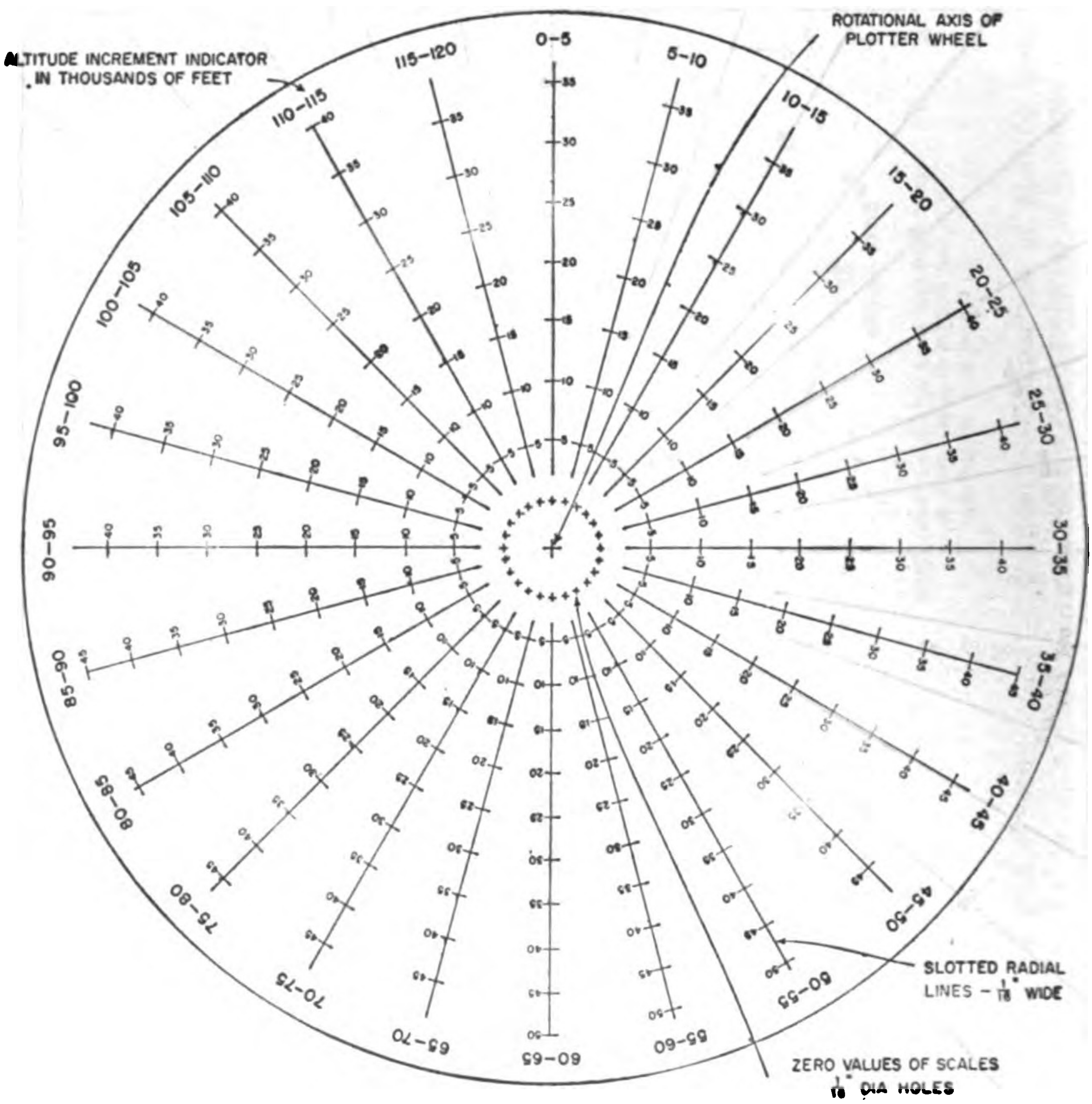


Figure 4.—Plotter wheel for determining displacement of 75-μ particles.

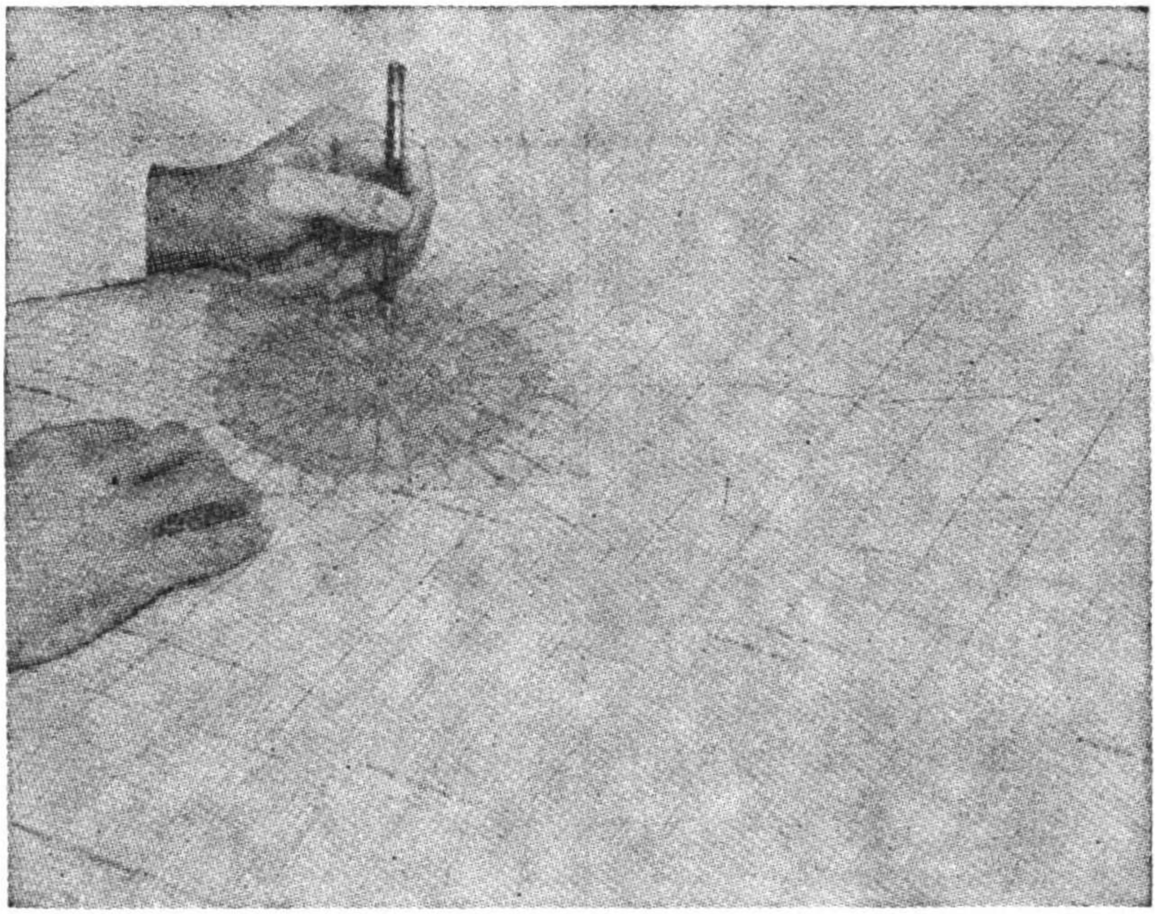


FIGURE 5.—Plotting device being used.

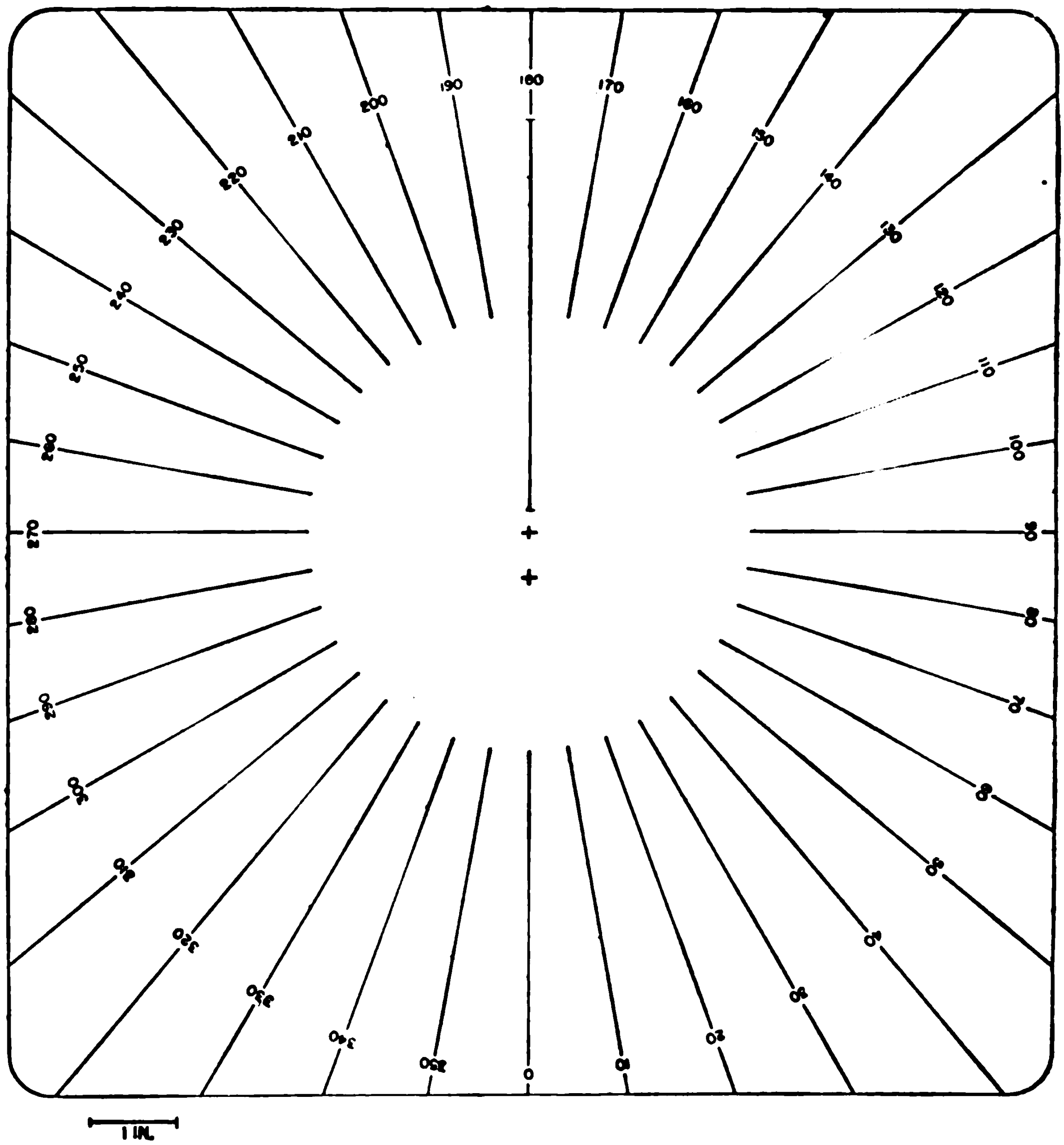


FIGURE 6A.—Plotter base for 75- and 100-μ particles.

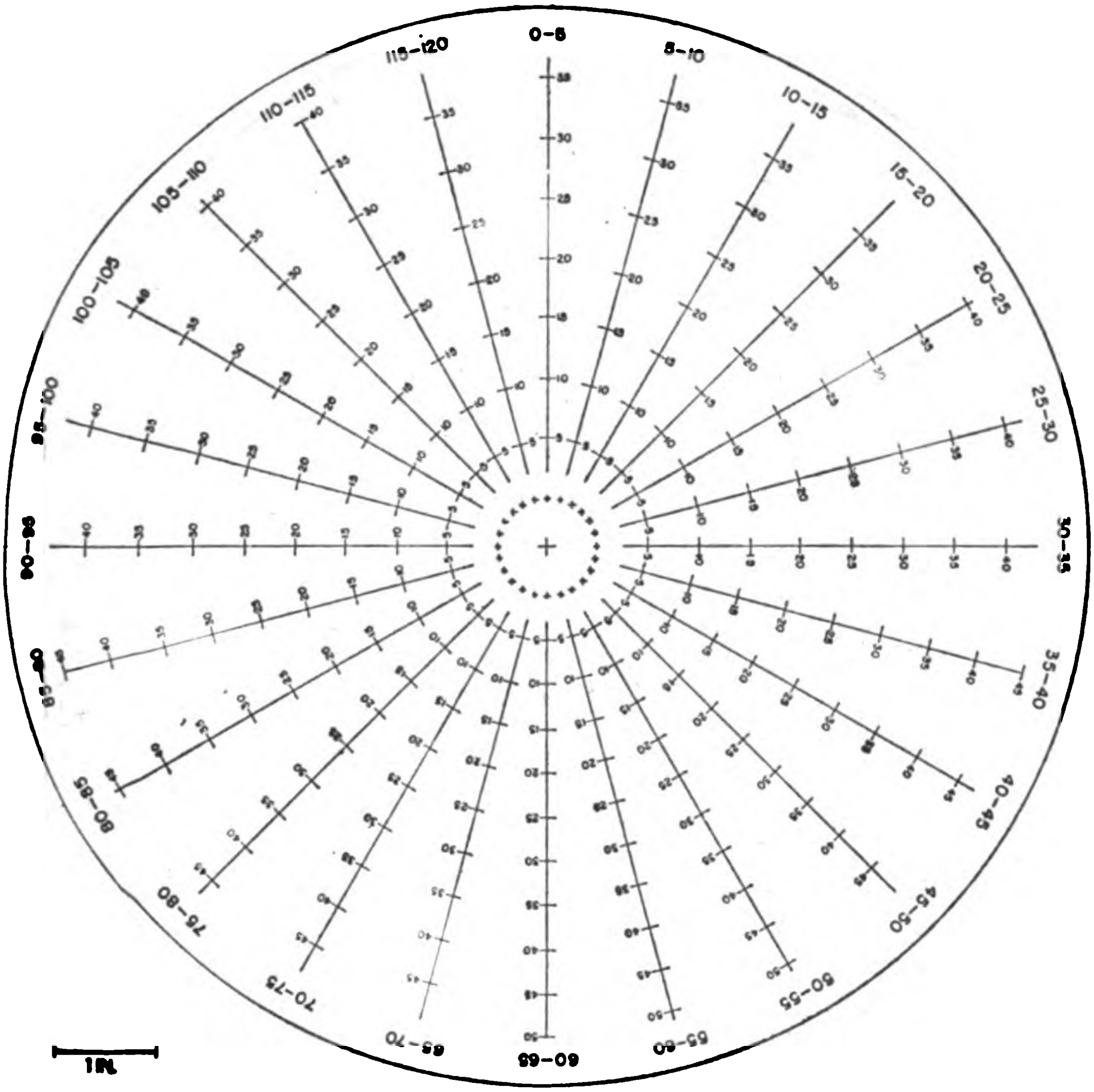


FIGURE 6B.—Plotter wheel for 75-μ particle.

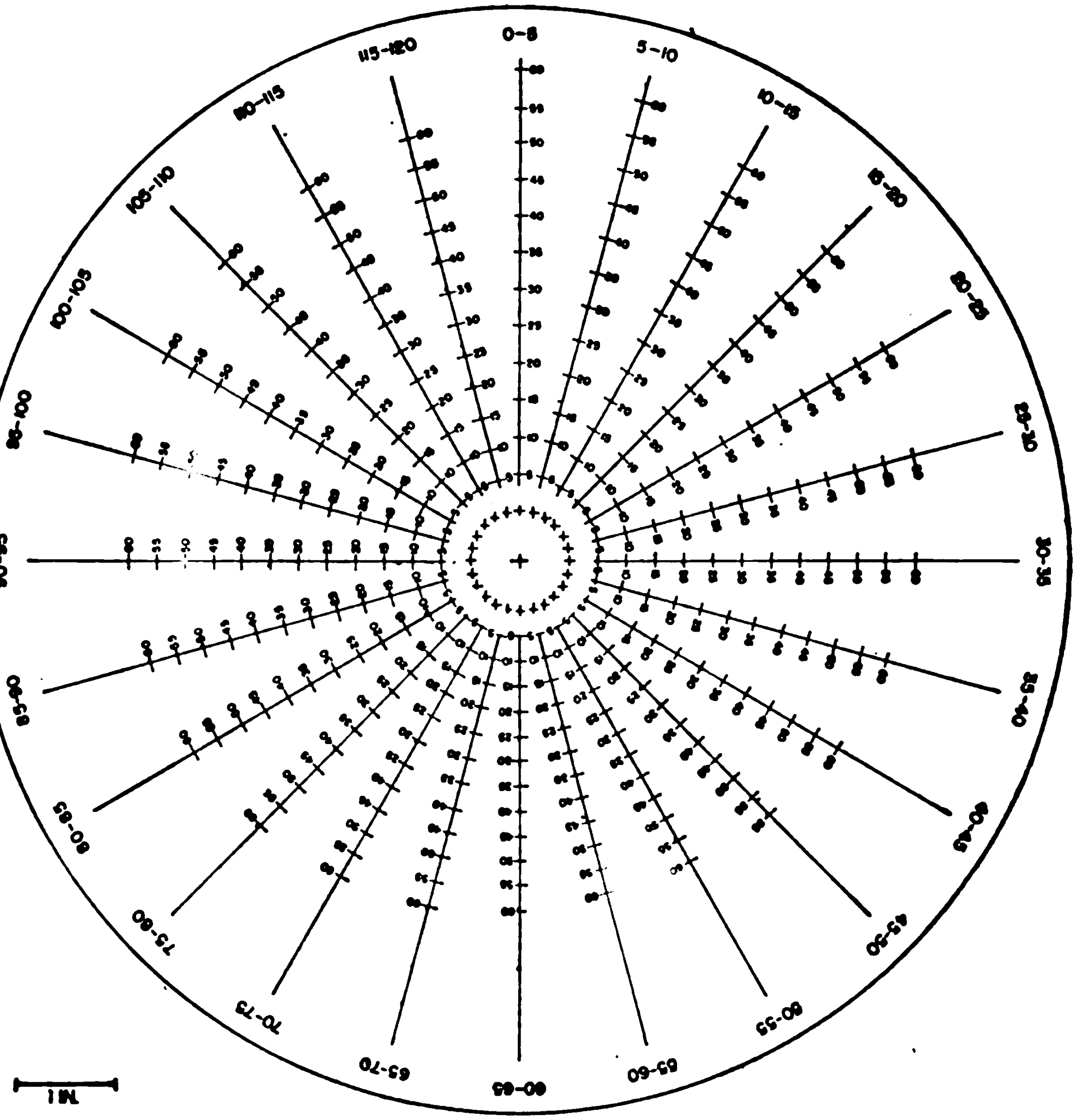


Figure 6C.—Plotter wheel for 100-μ particle.

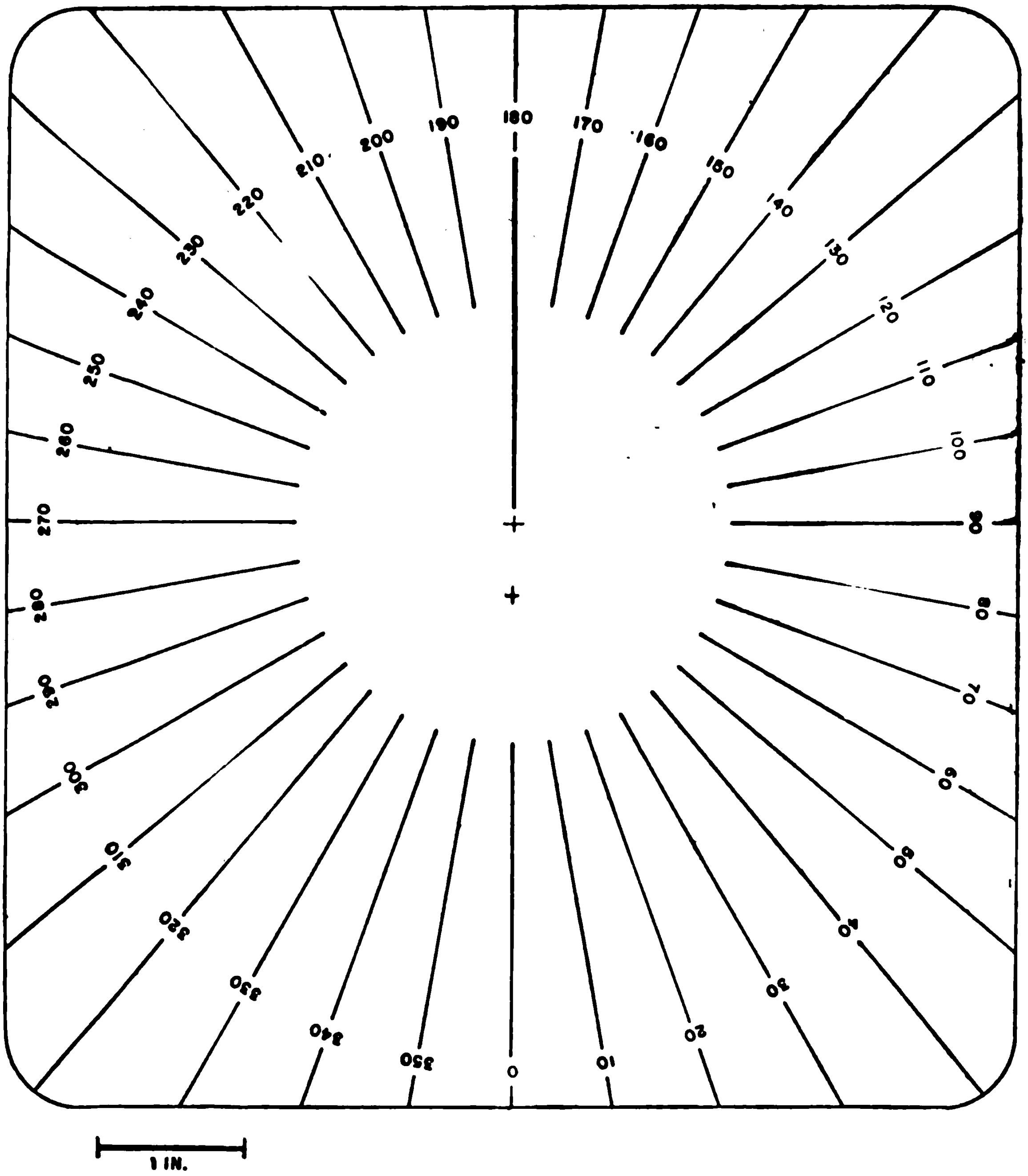


FIGURE 7A.—Plotter base for 200- and 350-μ particles.

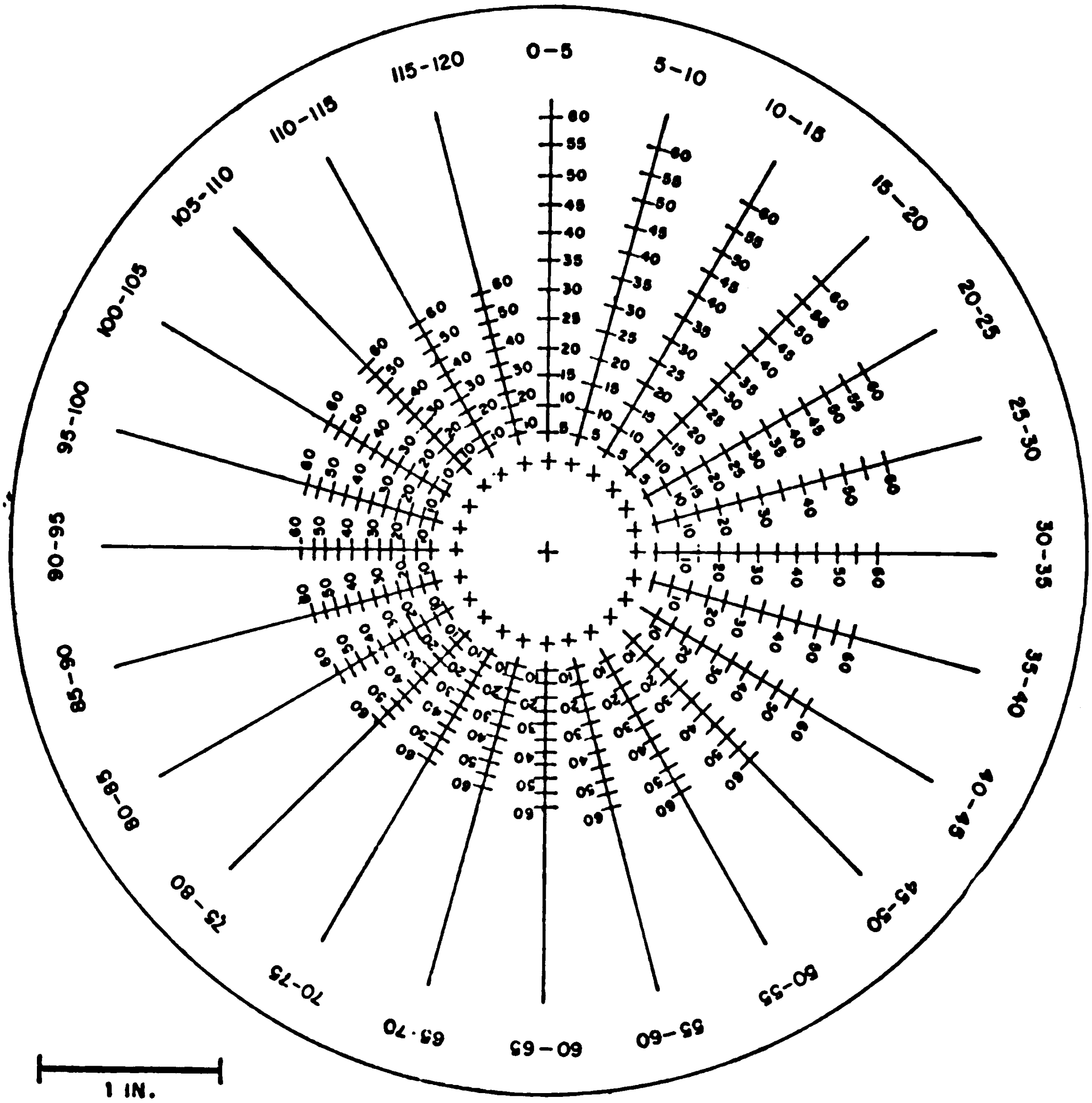


FIGURE 7B.—Plotter wheel for 200-μ particle.

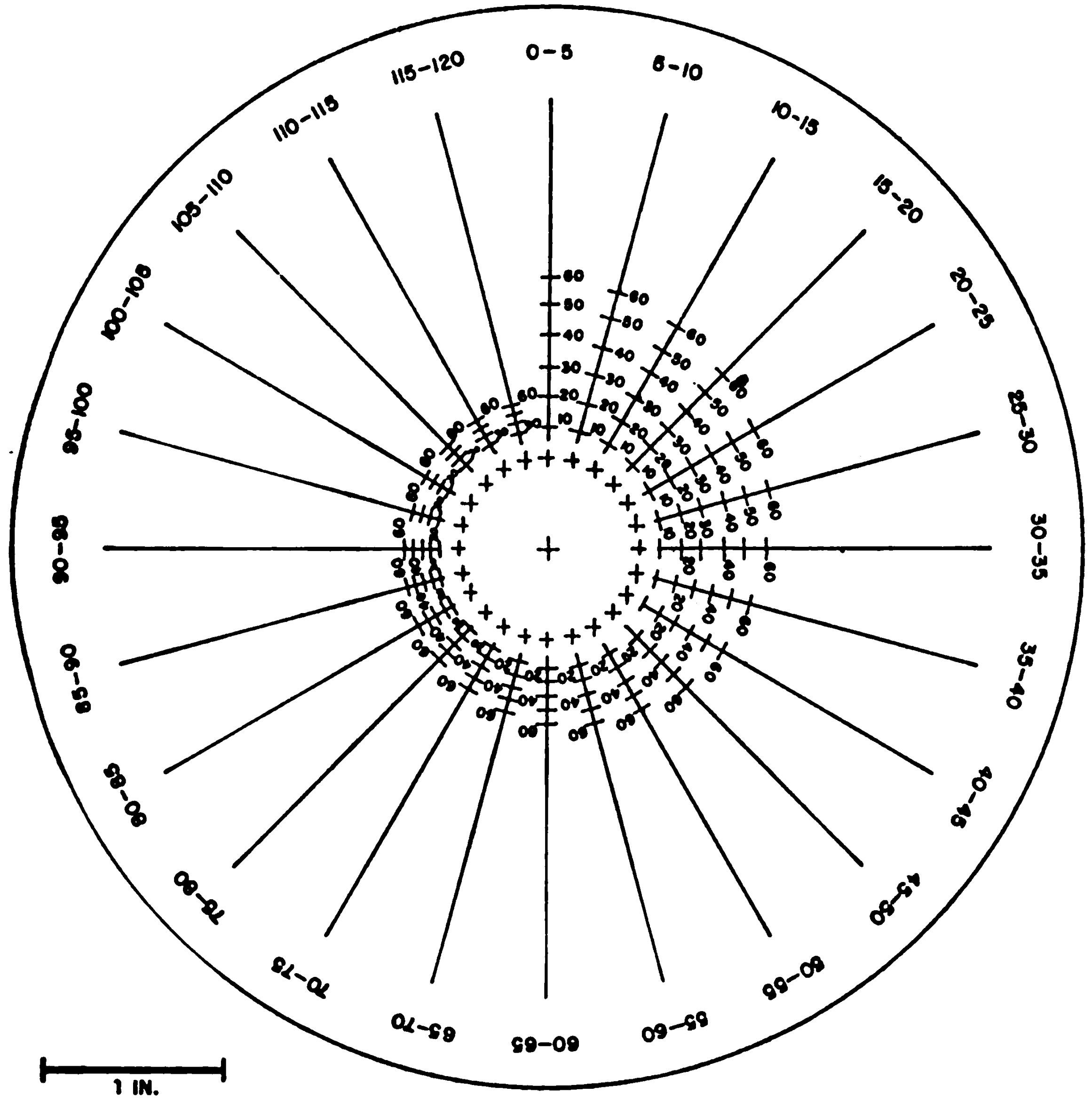


FIGURE 7C.—Plotter wheel for 850-μ particle.

Naval Radiological Defense Laboratory. USNRDL-TR-127. A FALLOUT PLOTTING DEVICE, by E. A. Schuert. 30 Nov. 1956. 19 p. illus. UNCLASSIFIED A fallout plotting device was developed. The method requires no drafting equipment and is ideally suited for field use. At Operation REDWING it was found that untrained personnel could quickly become proficient in its employment.	1. Fallout - Course mapping 2. Plotters I. Schuert, E. A. II. Title. III. NS 081-001. UNCLASSIFIED

A Fallout Forecasting Technique With Results Obtained at the Eniwetok Proving Ground [Draft]

E. A. Schuert, USNRDL TR-139, United States Naval Radiological Defense Laboratory, San Francisco, Calif.

ADMINISTRATIVE INFORMATION

The work described herein is a part of the research sponsored by BuShips and the United States Army and locally designated as program 2, problem 3, phase 3. Its technical objective is AW-7 and it is described on RDB card NS 081-001.

SUMMARY

The problem: A fallout forecasting technique is needed to qualitatively describe the fallout hazard resulting from nuclear detonations. This technique should have such flexibility that its employment is valid for field use.

Findings: A summary of the latest experimental and theoretical considerations has resulted in the development of a technique whose complexity is dependent on the required accuracy of the results desired. This technique has been satisfactorily tested at the Eniwetok Proving Grounds for land surface and water surface bursts.

ABSTRACT

A generalized fallout forecasting technique is presented with detailed computations of input parameters for use in the Marshal Islands.

Results obtained at a recent weapons test are briefly discussed by comparison of forecast fallout with preliminary measured data.

1. INTRODUCTION

Fallout research continues to seek a theoretical working model that will describe in detail the mechanism of fallout. Aside from this long-range problem, consideration must be given to making available a working tool that will meet the needs of the military for solving fallout problems in the field. Such consideration requires a simplified rapid system capable of producing qualitative if not quantitative results.

Within a program studying fallout at a recent weapons test operation there was a fallout forecasting assignment that had many aspects of the practical

field problem yet, at the same time required quantitative results for use in reducing other data. This program needed positioning data such that three ships could be located properly in the fallout to obtain data on its parameters. Also, aerial and oceanographic survey projects required knowledge of the fallout to instigate their navigational procedures properly.

To meet these requirements a technique for rapid fallout forecasting was developed which not only satisfied the needs of the fallout program but also was accurate enough to allow comparison between meteorological aspects of model work and results obtained from surface measurements. This technique was restricted to describing quantitatively the perimeter of the fallout, the axis of the "hot line," and to determining the time of arrival of fallout throughout the pattern. No attempt was made to quantitate the expected levels of gamma activity or to develop radiation contour lines.

The task force employed a fallout prediction unit at this operation for determining the safe time to detonate the test devices. Many of their techniques for forecasting were similar to those described in this report, however, their problem was of a different nature than that of the fallout program. Several of their methods were unique in that portable analog computers were tested as field instruments. These computers permitted consideration of many complex parameters. One, in particular, obtained essentially an instantaneous solution to the problem once the meteorology was available.

The fallout program and the task force prediction unit functioned independently. It was not feasible for the two to employ the same technique because the postshot variability of the winds aloft were especially critical in ship-location problems in the fallout program. This problem will be discussed in detail later.

1.1 Objective

This report describes a technique of forecasting fallout employed at a recent weapons-test operation. The results obtained in the field are discussed as examples of the reliability of the techniques. Although the technique was designed for analysis ot land surface detonations where the fallout is particulate, its application to water surface detonations is considered.

2. FORECASTING TECHNIQUE

The forecasting technique uses many ideas from fallout model work. Several simplifications as well as a plotting device have been developed to the end that the time involved has been reduced greatly without sacrificing accuracy. In general, an initial source of activity is defined describing the "stabilized" nuclear cloud by appropriate spatial and size distributions of radioactive particles. These particles are tracked to the earth's surface by considering their falling speeds and effects of the winds existing aloft.

2.1 Basic considerations

In some cases the input parameters for the forecasting technique were obtained from weapon-test measurements. In others where data were lacking, the parameters were derived from theory.

2.1.1 Source model

The optical or visible dimensions of the initial cloud from a nuclear detonation have been documented in past weapons tests. Available data describe such parameters as height to base of mushroom, height to top of mushroom, and mushroom diameter all as functions of time. Vertical rise stabilizes in approximately 6 min post detonation. This time is independent of yield, however, the expansion of the mushroom diameter particularly for the megaton devices continues for perhaps 30 min. Available diameter measurements have not been made in excess of H+10 min, however, fairly reliable data are known for the optical cloud dimensions as functions of yield to H+10 min. The ultimate cloud diameter can be extrapolated from low-yield curves and some qualitative data. Figures 1 and 2 present values of the cloud dimensions from past tests. The source model was assumed cylindrical having, for a given yield, these dimensions. Its stem diameter was taken as 10 percent of mushroom diameter.

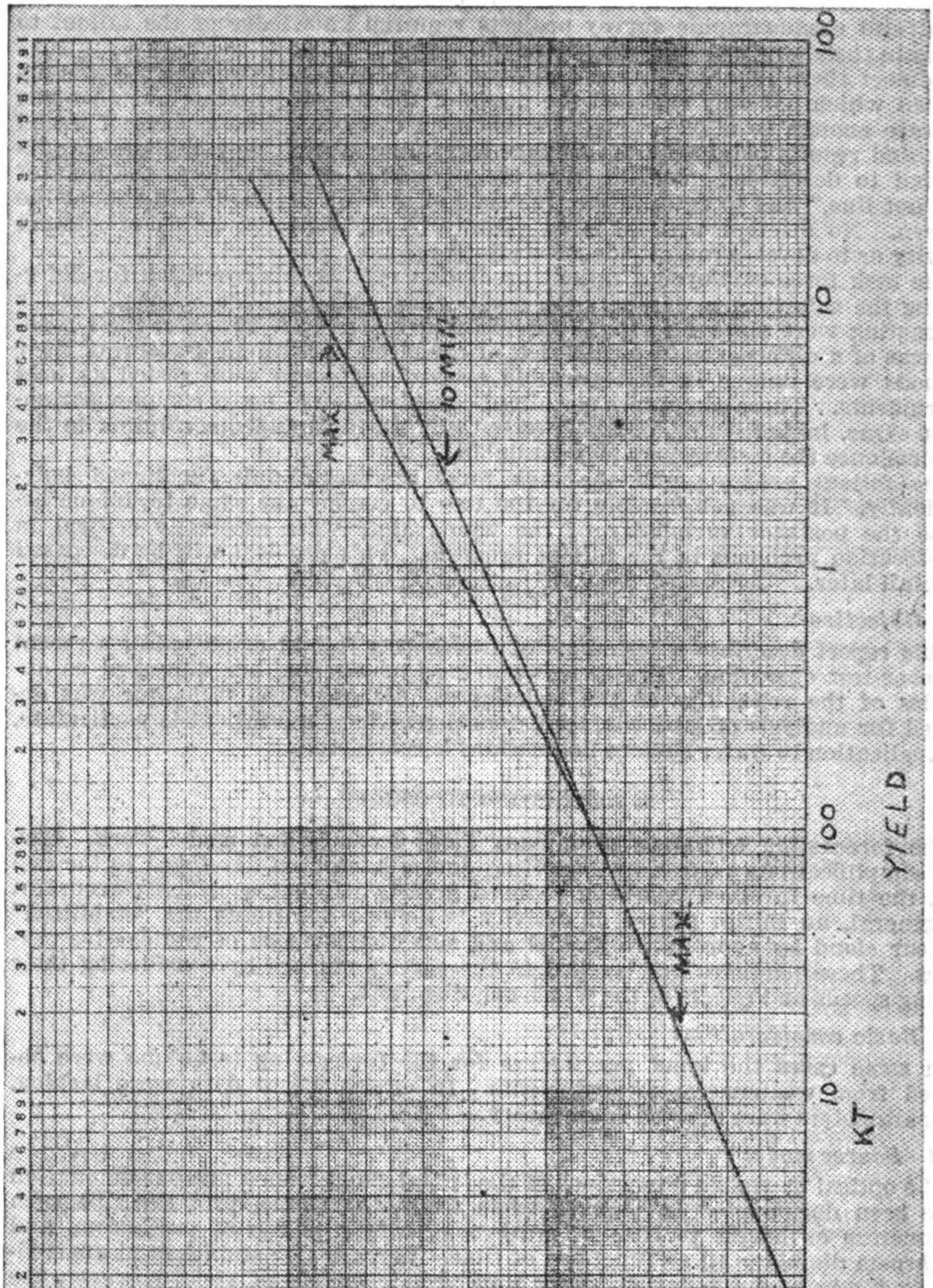


FIGURE 1.—Mushroom diameter as a function of yield.

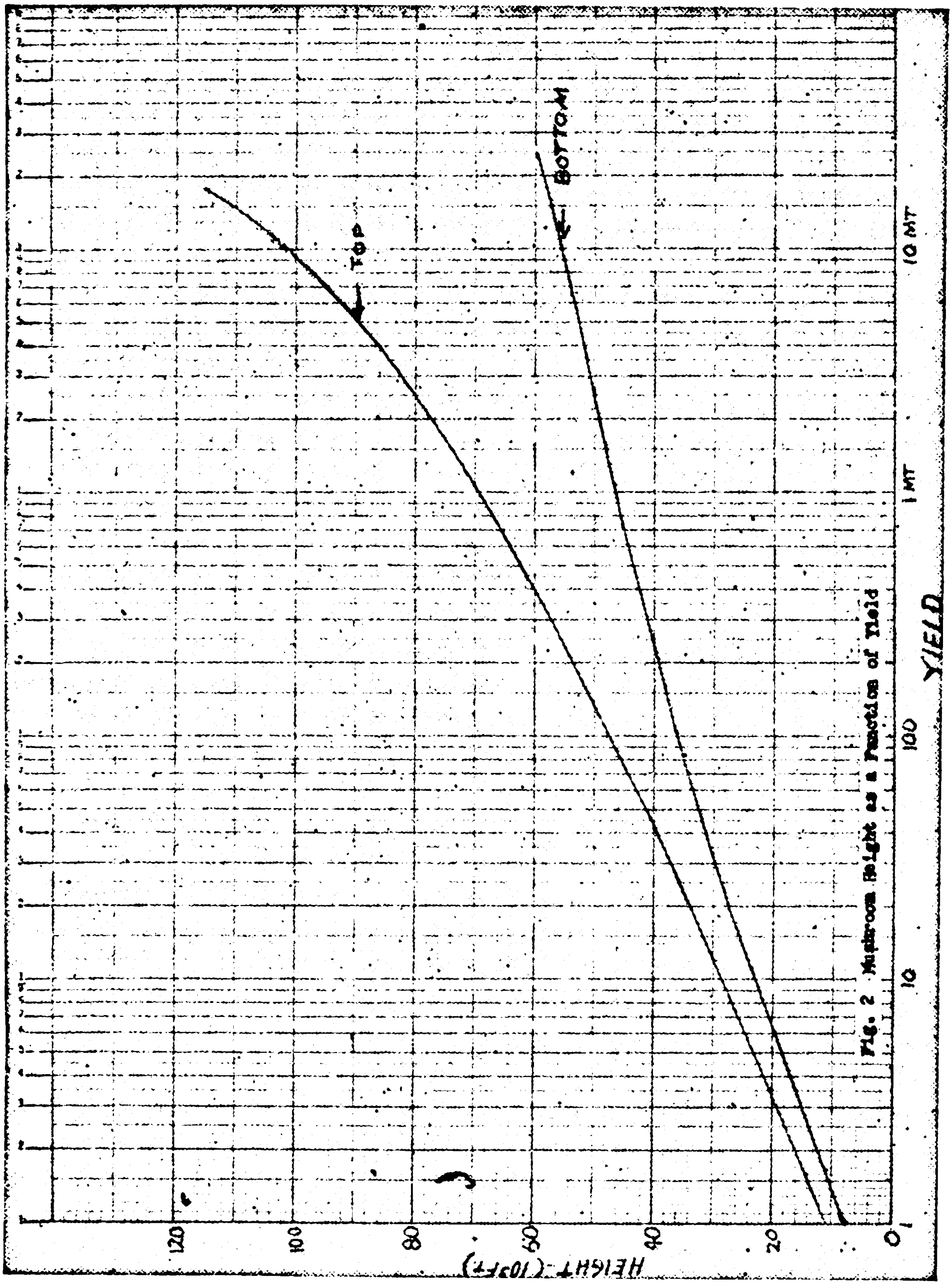


Fig. 2 Mushroom Height as a Function of Yield

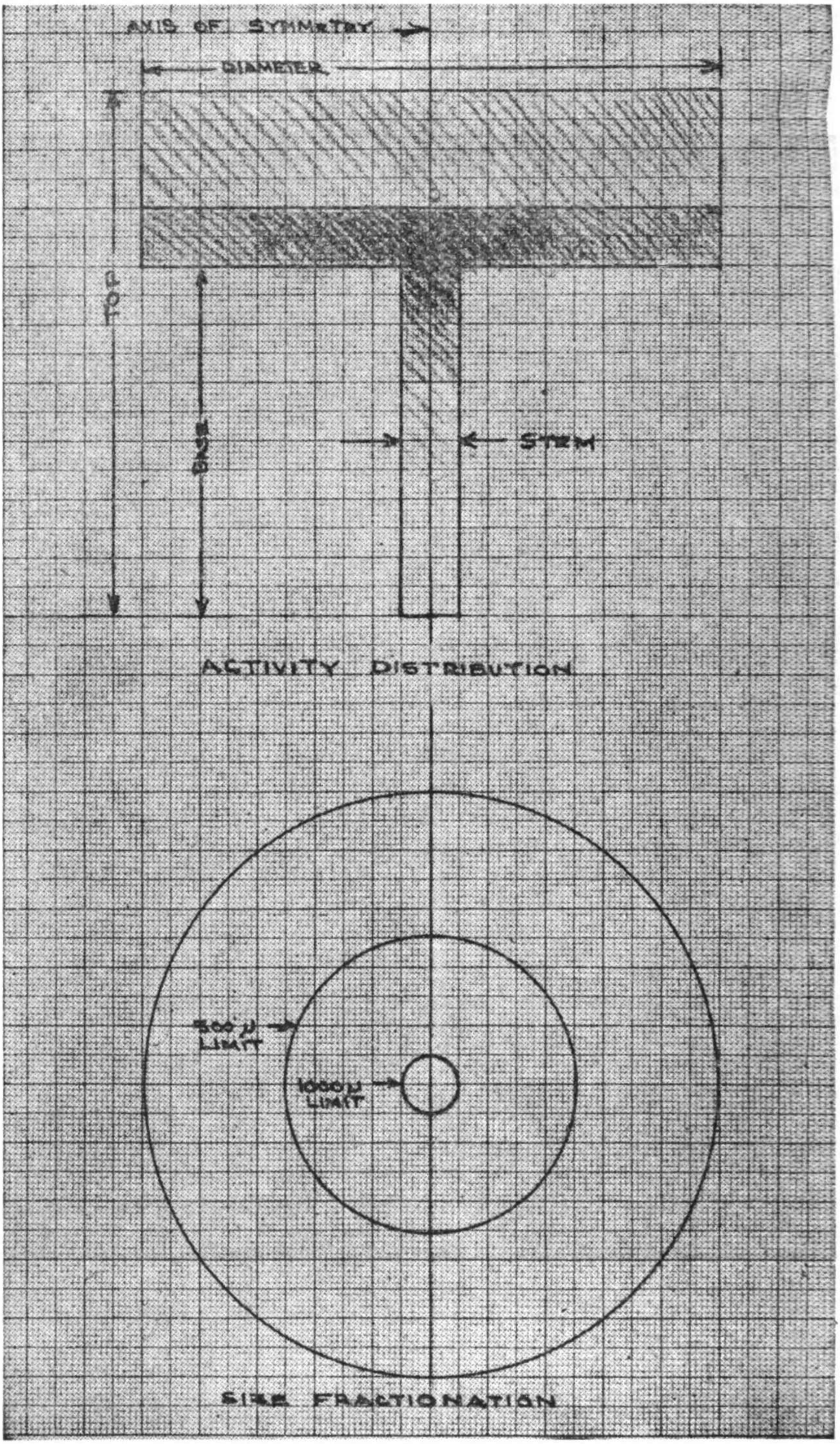


FIGURE 3.—Source model.

2.1.2 Activity distribution in source model

The great part of the activity was assumed to be concentrated in the lower third of the mushroom. The lower two-thirds of the stem was ignored; the remainder of the stem and upper two-thirds of the cloud were weighted lightly. This description (fig. 8) of the activity distribution within the cloud appeared most reasonable in the light of available data and logical theoretical considerations. The activity was concentrated nearer the axis of symmetry of the cloud than at its outer edges.

2.1.3 Particle size distribution in source model

All particle sizes were assumed at all elevations within the cloud except the lower two-thirds of the stem. However, to obtain agreement with past fallout measurements and with the optical diameter of the mushroom, it was necessary to fractionate the particle size distribution radially within the cloud. Otherwise, the computed fallout area about ground zero would be too large. The fractionation was specified as follows: particles of 1,000 microns in diameter and larger were restricted to the inner 10 percent of the mushroom radius or approximately the stem radius; those from 500 to 1,000 microns in diameter were limited to the inner 50 percent of the cloud radius. Since the relation of activity to particle size is some function of the particle diameter this fractionation tends to concentrate the activity about the axis of symmetry of the cloud.

2.1.4 Particle falling speeds or settling rates

Computations of the terminal velocities of the particles were based on aerodynamic considerations for a still atmosphere having temperature and density distributions typical of the Marshall Islands atmosphere in the spring months.

Experimental data from past tests at Eniwetok Atoll indicated that the particles were irregular in shape and had a mean density of 2.36 g/cu cm.

It can be shown that particles falling at their terminal speed experience three types of flow in a fluid: streamline or laminar flow where viscous forces predominate, ($10^{-4} \leq R_e \leq 2.0$); intermediate flow where inertia forces predominate, ($2 \leq R_e \leq 500$); turbulent flow where inertia forces predominate, ($500 \leq R_e \leq 10^5$). Below a Reynolds number of 10^{-4} certain corrections must be applied to the equations because the particle diameter approaches the mean free path of the fluid medium; the region above a Reynolds number of 10^5 is important only in ballistics. These limiting cases will not be discussed here.

The parameters actively affecting a particle's falling speed are: its weight, its drag coefficient, its density, as well as the fluid density and fluid viscosity.

Most empirical equations developed in past experimental work have been for spheres dropped in various liquids. Some work has been done on irregular shaped particles and some done in wind tunnels. The equations[1] used to determine the falling rates for particles in a fluid medium follow.

For Streamline motion, $10^{-4} \leq R_e \leq 2.0$

$$V_s = K_s \left(\frac{\rho-\rho_o}{\rho_o}\right)(d^2)\left(\frac{\mu}{\rho_o}\right)^{-1} \qquad (1)^2$$

where

V_s = terminal velocity in cm/sec
ρ = particle density in gms/cm³
ρ_o = fluid density in gms/cm³
d = particle diameter in cm
μ = absolute viscosity of fluid in poises
K_s = constant incorporating gravity
= 54.5 for spheres
= 36.0 for irregular shaped particles.

The limiting diameter to which Eq. 1 holds is

$$d' = \left(\frac{36\mu^2}{g\rho_o(\rho-\rho_o)}\right)^{1/3}$$

for spheres and

$$d' = \left(\frac{54.4\mu^2}{g\rho_o(\rho-\rho_o)}\right)^{1/3}$$

for irregular shaped particles.

[1] J. M. Dallavalle, Mircomeritics, Pittman Publishing Corp., 1948.

For Intermediate motion, $2.0 \leq R_e \leq 500$

$$V_I = K_I \left(\frac{\rho - \rho_o}{\rho_o}\right)^{2/3} \left(\frac{\mu}{\rho_o}\right)^{-1/3} d_o \qquad (2)^1$$

where $d_o = d - \xi d'$
$\xi = 0.4$ for spheres
$\xi = 0.279$ for irregular shapes
d' = limiting diameter to which streamline motion applies
$K_I = 30.0$ for spheres
$= 19.0$ for irregular shapes.

The limiting diameter to which the Eq. 2 holds is

$$d'' = 43.5 \left(\frac{\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for spheres

$$d'' = 51 \left(\frac{\mu^2}{g\rho_o(\rho - \rho_o)}\right)^{1/3}$$

for irregular shapes.

For Turbulent motion, $500 \leq R_e \leq 10^5$

$$V_T = K_T \left[\left(\frac{\rho - \rho_o}{\rho_o}\right) d\right]^{1/2} \qquad (3)^1$$

$K_T = 54.6$ for spheres
$= 50.0$ for irregular particles.

The question of particle diameter becomes puzzling when the equations are applied to irregular shaped particles. Although the equations for irregular shaped particles cannot be applied to an individual particle, they are assumed valid in establishing the average falling rates of many irregular particles clustered about this defined size.

2.1.5 *Marshall Islands atmosphere*

Marshall Islands atmospheric conditions determined the values for the density and viscosity parameters used in computing particle falling rates. Available data on the temperature, pressure, density, and viscosity as functions of altitude for the atmosphere common to the Marshall Island area in the spring months follow.

It was not possible to use a "standard atmosphere" in this problem because such use introduced a large error in the particle falling rate at high altitudes. This error originates primarily because of the assumed isothermal layer above the tropopause.

2.1.5.1 *Temperature distribution*

From the weather data published by Task Force Weather Central at Operation Castle, four published radiosonde runs obtained temperature measurements to high altitudes:

March 1, 1954, 0600 M Bikini
March 27, 1954, 0600 M Bikini
April 7, 1954, 0620 M Bikini
April 26, 1954, 0610 M Bikini

No data were available above 67,000 feet. Fortunately two of these runs penetrated the tropopause which was located at approximately 55,000 feet. To extend the measured data beyond 67,000 feet climatological averages[3] for latitude 12° North were employed. Agreement with measured data was satisfactory except for the range from 50,000 to 65,000 feet where the climatological data indicated a well-defined isothermal layer. The most significant finding from the measured data was the complete lack of an isothermal layer above the tropopause. Instead, a distinct and rapid inversion was observed which when extrapolated as a straight line agreed with the climatological data above 70,000 feet. Since the atmosphere was to be defined to 120,000 feet further extrapolation was necessary. The only temperature data available at these higher altitudes were taken by rockets[4] over White Sands, N. Mex. A plot of 3 points from the rocket data justifies to some extent a continued extrapolation of the curve to 120,000 feet.

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[1] These equations were taken from reference 1; however, certain constants have been reevaluated.
[3] Brunt, David, Physical and Dynamical Meteorology, the University Press, 1941.
[4] Chief of Naval Operations, A Study of the Atmosphere Between 30,000 and 100,000 Feet (preliminary report), September 1948.

Therefore the profile of the vertical temperature gradient (fig. 4) was based on measured data to 67,000 feet and extrapolated to 120,000 feet on the basis of supporting climatogical data and temperature measurements made at high altitudes with rockets.

2.1.5.2 Pressure distribution

Published high altitude measurements of the pressure distribution were obtained on two occasions at Operation Castle. These measurements[5] were made at Bikini on April 7 and 26, 1954, and were not taken above 65,000 feet. Above this altitude the pressure was extrapolated as a straight line on semilog paper to 120,000 feet. Agreement with published rocket data from White Sands, N. Mex., was good to 90,000 feet (fig. 5).

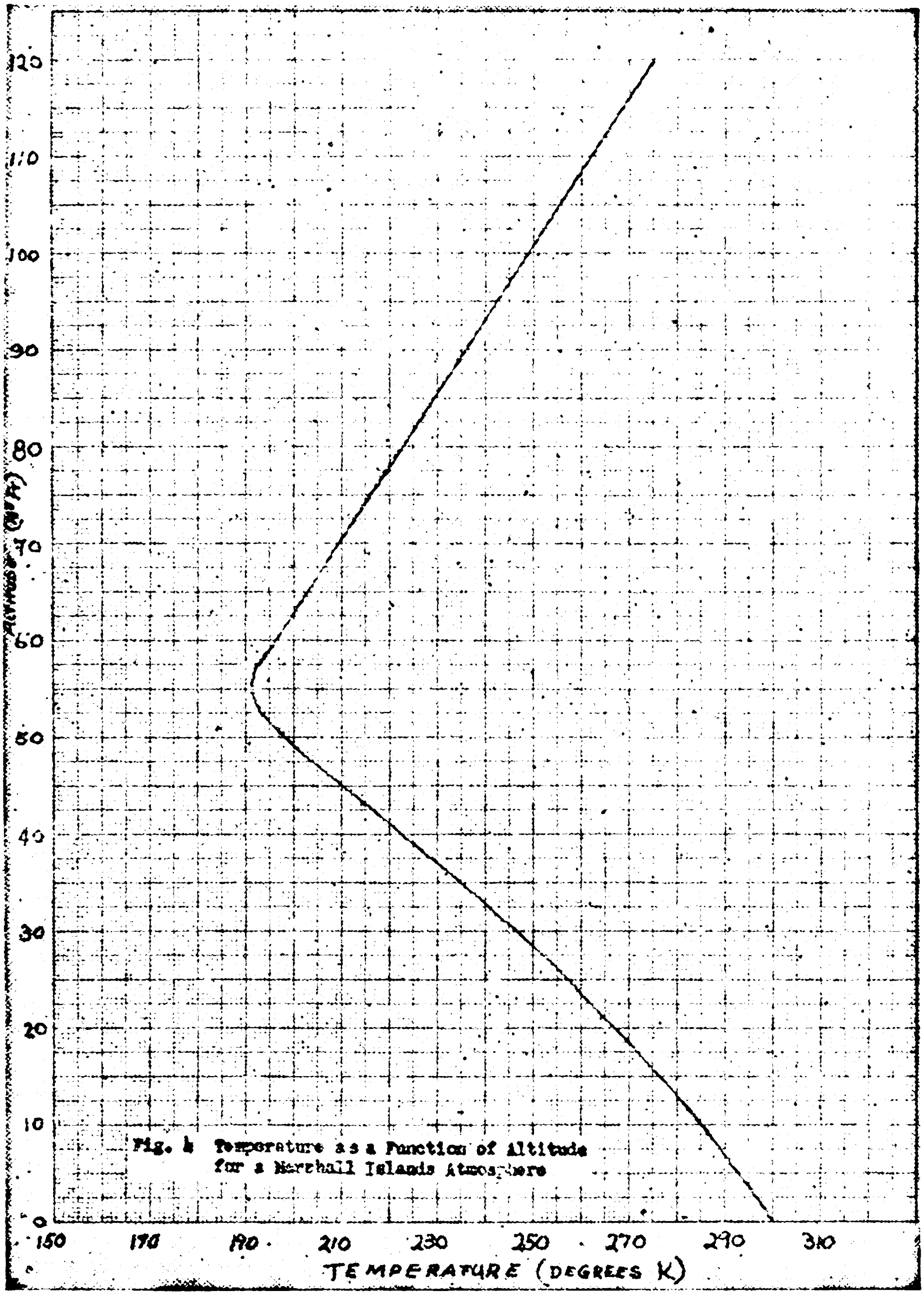


Fig. 4 Temperature as a Function of Altitude for a Marshall Islands Atmosphere

[5] Hq. T. U.-13 operation memo No. 14, April 30, 1954.

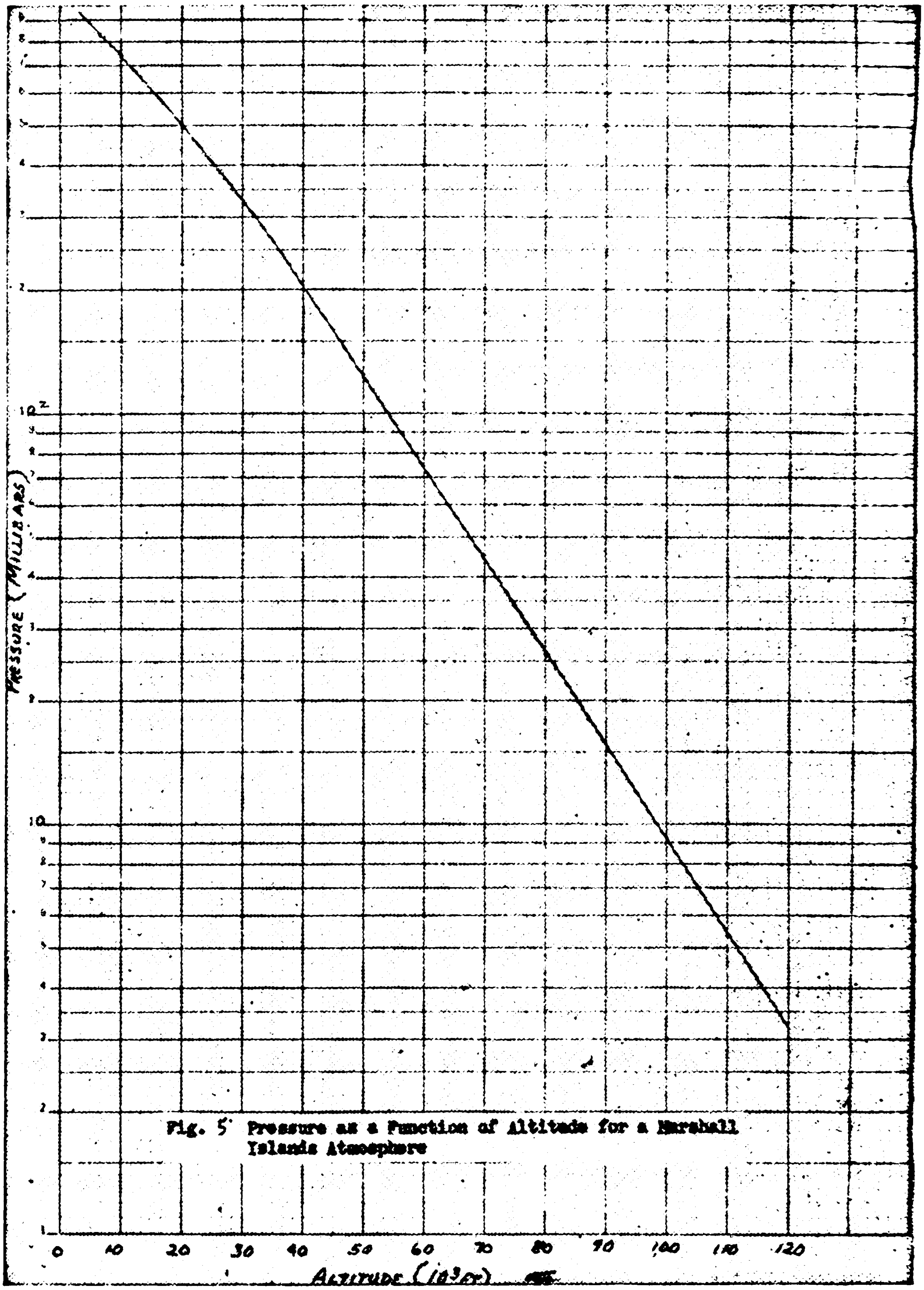


Fig. 5 Pressure as a Function of Altitude for a Marshall Islands Atmosphere

2.1.5.3 Density distribution

The density distribution of the atmosphere (fig. 6) was calculated from the perfect gas law using the above pressure and temperature distributions,

$$\rho=\frac{P}{RT}$$

where the gas constant was taken for dry air. This assumption of no moisture in the mixture introduces an error of several percent in the lower layers of the atmosphere where the relative humidity is high; however, it can be safely neglected. As well, the latest theories on the composition of the atmosphere indicate it to be constant to altitudes above 150,000 feet which justified the assumption of a nonvarying gas constant.

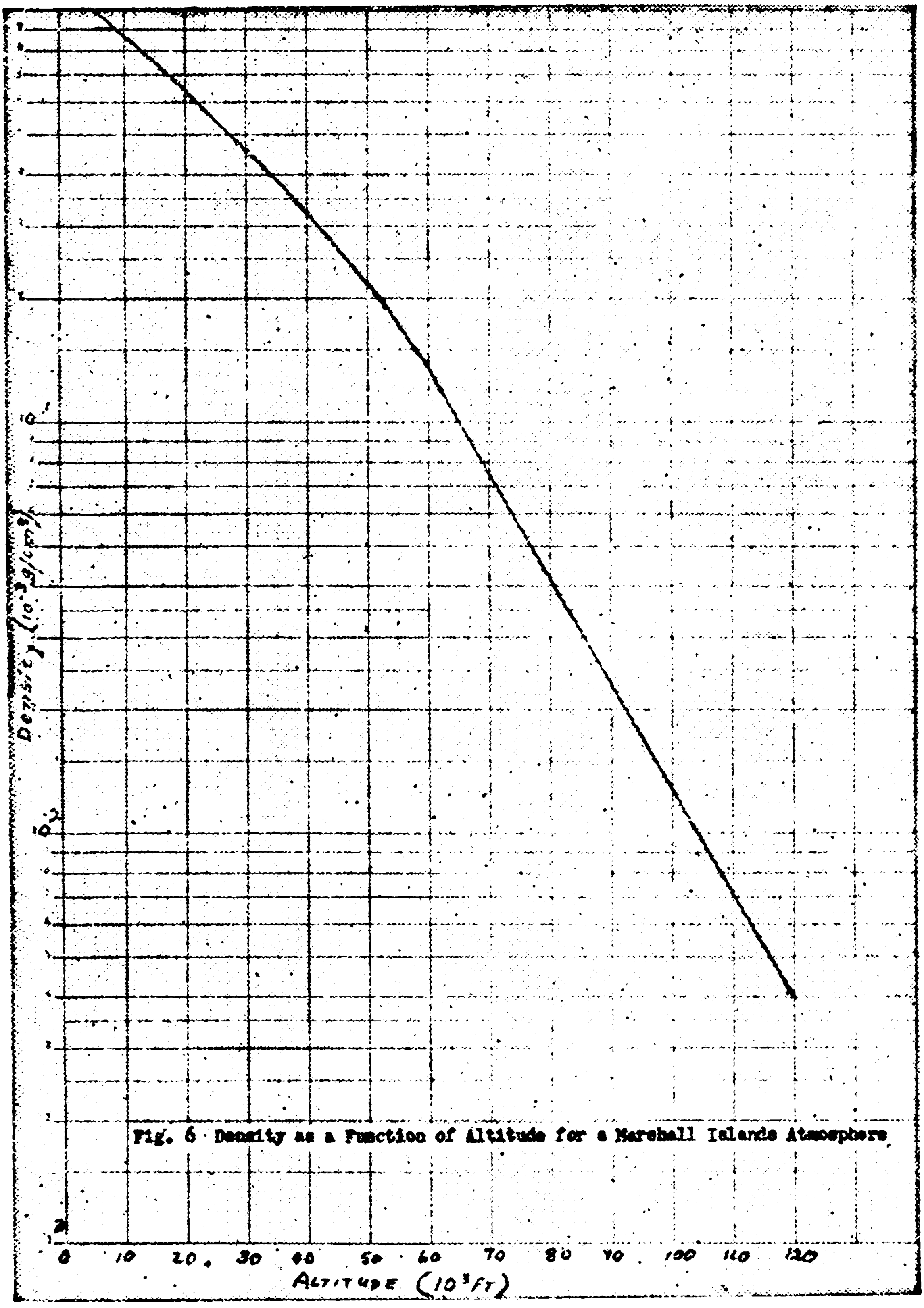


Fig. 6 Density as a Function of Altitude for a Marshall Islands Atmosphere

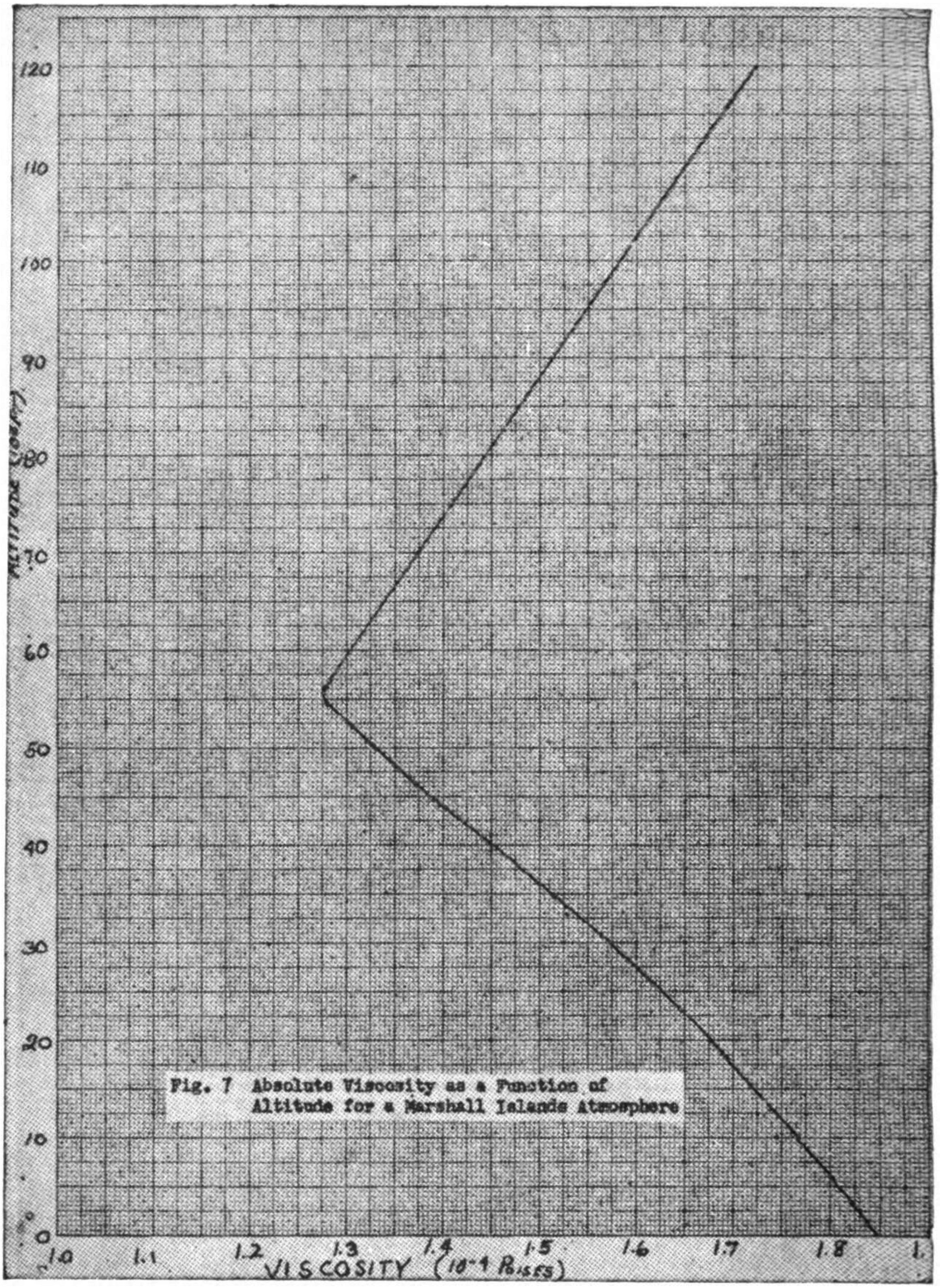


Fig. 7 Absolute Viscosity as a Function of Altitude for a Marshall Islands Atmosphere

2.1.5.4 *Viscosity distribution*

The variation of absolute viscosity with altitude was computed from the observed temperature distribution using Sutherland's formula,[6]

$$\mu = u_o \left(\frac{T_0+114}{T+114}\right)\left(\frac{T}{T_o}\right)^{3/2}$$

$$u=0.01709\left(\frac{387.17}{t_i+114}\right)\left(\frac{t_i}{273.17}\right)^{3/2}$$

where t_i equals temperature in degrees Kelvin and μ is viscosity in centipoises. These data are plotted in figure 7.

The data on pressure, temperature, density, and viscosity in 1,000-foot intervals to 120,000 feet are summarized in table 1.[7]

TABLE 1.—*Table of temperature, pressure, density, and viscoscity of the atmosphere over the Marshall Islands during the spring*

Altitude (feet)	Temperature °K	Pressure (Mb)	Density (g/cm³·10³)	Viscosity (poises·10⁴)
SFC	300	1,006	1.17	1.84
1,000	299	980	1.13	1.83
2,000	297	950	1.10	1.825
3,000	296	930	1.06	1.815
4,000	295	900	1.03	1.810
5,000	293	870	1.0	1.805
6,000	292	850	.97	1.795
7,000	290	820	.94	1.786
8,000	289	800	.91	1.780
9,000	288	770	.88	1.770
10,000	285	740	.86	1.765
11,000	284	720	.83	1.775
12,000	282	690	.80	1.745
13,000	280	660	.78	1.740
14,000	278	640	.76	1.730
15,000	276	620	.73	1.720
16,000	274	590	.71	1.715
17,000	273	570	.69	1.705
18,000	271	550	.67	1.695
19,000	269	530	.65	1.686
20,000	267	500	.63	1.675
21,000	265	480	.61	1.665
22,000	263	460	.59	1.655
23,000	261	440	.57	1.645
24,000	259	420	.55	1.635
25,000	257	410	.53	1.625
26,000	255	390	.52	1.615
27,000	252	370	.50	1.600
28,000	250	355	.49	1.590
29,000	248	340	.47	1.580
30,000	246	320	.45	1.570
31,000	243	310	.43	1.560
32,000	241	300	.42	1.545
33,000	239	280	.41	1.535
34,000	236	270	.39	1.525
35,000	234	260	.38	1.510
36,000	232	245	.37	1.500
37,000	230	235	.36	1.490
38,000	227	225	.35	1.475
39,000	225	215	.33	1.465
40,000	223	205	.32	1.450
41,000	220	195	.31	1.440
42,000	218	185	.30	1.430
43,000	215	175	.29	1.420
44,000	213	165	.28	1.405
45,000	211	160	.27	1.395
46,000	209	150	.26	1.380
47,000	206	145	.25	1.370
48,000	204	135	.24	1.355
49,000	201	130	.23	1.345
50,000	199	125	.22	1.335
51,000	196	115	.21	1.320
52,000	194	110	.20	1.310
53,000	193	105	.19	1.295
54,000	192	100	.18	1.285

[6] Smithsonian Physical Tables, 1954.

[7] A great deal of excellent upper air data for the Marshall Islands was obtained at Operation Redwing in 1956. Reduction of these data will result in a much better description of the Marshall Islands atmosphere than has been previously available.

TABLE 1.—*Table of temperature, pressure, density, and viscosity of the atmosphere over the Marshall Islands during the spring*—Continued

Altitude (feet)	Temperature °K	Pressure (Mb)	Density ($g/cm^3 \cdot 10^3$)	Viscosity (poises·10^4)
55,000	191	95	.17	1.275
56,000	191	90	.16	1.275
57,000	192	85	.155	1.280
58,000	193	80	.145	1.290
59,000	194	77	.14	1.295
60,000	195	73	.135	1.300
61,000	197	70	.125	1.310
62,000	198	66	.115	1.320
63,000	199	63	.110	1.325
64,000	201	60	.105	1.330
65,000	202	56	.10	1.340
66,000	203	53	.094	1.345
67,000	205	50	.088	1.350
68,000	206	48	.083	1.360
69,000	207	46	.078	1.365
70,000	208	43	.073	1.370
71,000	210	41	.070	1.380
72,000	211	39	.066	1.385
73,000	213	37	.062	1.395
74,000	214	35	.058	1.400
75,000	215	33	.054	1.405
76,000	217	32	.052	1.415
77,000	218	30	.049	1.420
78,000	219	28	.046	1.430
79,000	221	27	.044	1.435
80,000	222	26	.042	1.440
81,000	223	24	.039	1.450
82,000	225	23	.037	1.455
83,000	226	22	.034	1.465
84,000	227	21	.032	1.470
85,000	229	20	.030	1.480
86,000	230	19	.029	1.485
87,000	231	18	.027	1.490
88,000	233	17	.026	1.500
89,000	234	16	.024	1.505
90,000	235	15	.023	1.510
91,000	237	14.5	.0215	1.520
92,000	238	14	.0205	1.525
93,000	239	13	.019	1.535
94,000	241	12.5	.018	1.540
95,000	242	12	.017	1.550
96,000	243	11	.016	1.555
97,000	245	10.5	.015	1.565
98,000	246	10	.014	1.570
99,000	247	9.5	.0135	1.575
100,000	249	9	.0130	1.585
101,000	250	8.5	.0102	1.590
102,000	251	8	.01015	1.600
103,000	253	7.6	.0105	1.605
104,000	254	7.4	.010	1.610
105,000	255	7.0	.0095	1.620
106,000	257	6.6	.0090	1.625
107,000	258	6.2	.0085	1.635
108,000	259	6.0	.0080	1.640
109,000	261	5.6	.0075	1.650
110,000	262	5.4	.0070	1.655
111,000	263	5.1	.0068	1.660
112,000	265	4.9	.0064	1.670
113,000	266	4.6	.0060	1.675
114,000	267	4.4	.0056	1.685
115,000	269	4.2	.0054	1.690
116,000	270	3.9	.0050	1.700
117,000	271	3.7	.0048	1.705
118,000	273	3.6	.0044	1.710
119,000	274	3.4	.0042	1.720
120,000	275	3.2	.0040	1.725

2.1.5.5 Terminal velocity computations

The average falling speed through 5,000-foot layers was computed for 4 particle sizes over an altitude range from 0 to 120,000 feet. In these computations all in-flight transition of the particles from streamline to intermediate flow had to be considered through use of the plot shown in figure 8.

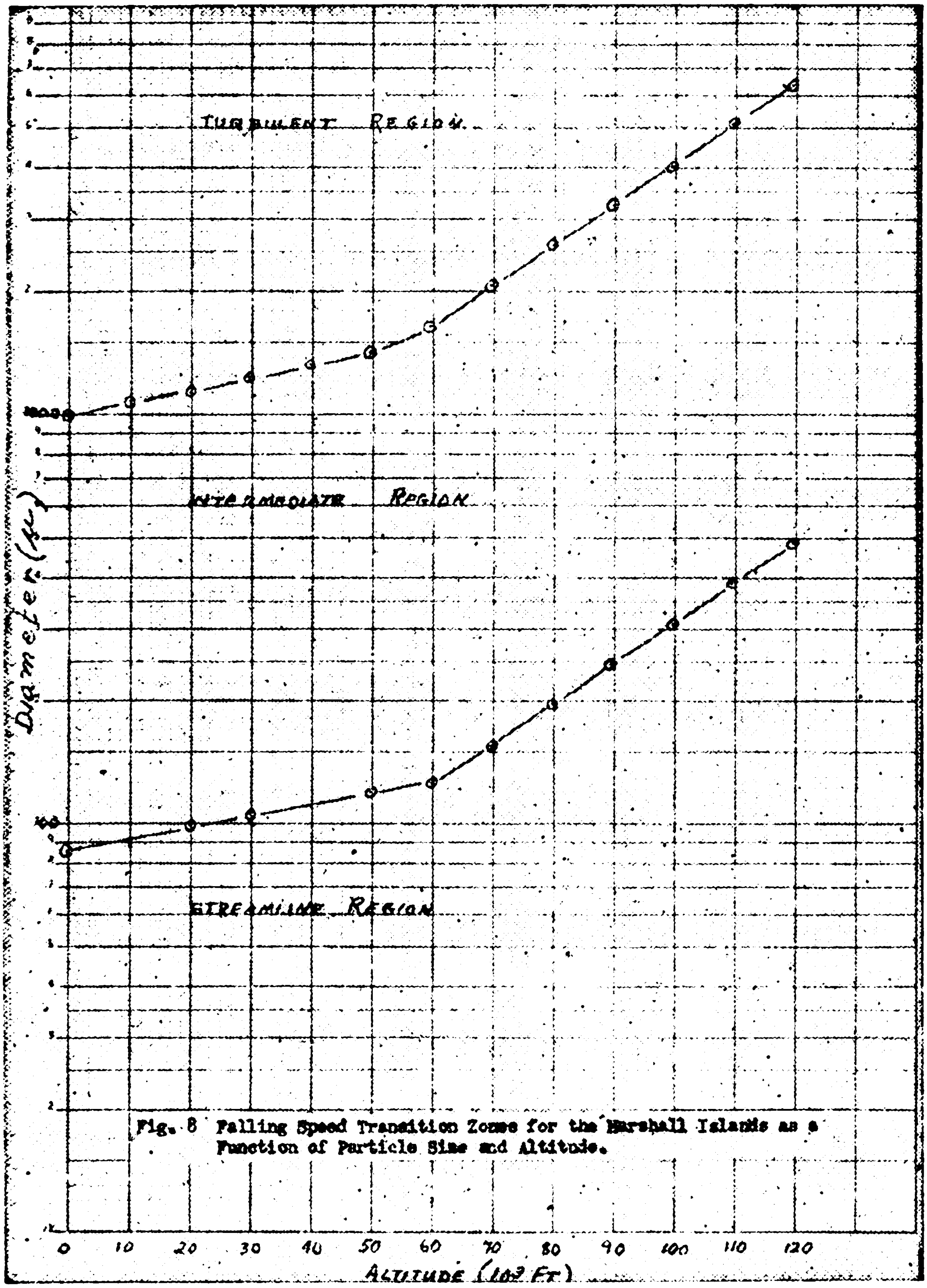


Fig. 8 Falling Speed Transition Zones for the Marshall Islands as a Function of Particle Size and Altitude.

Four particle sizes (75 μ, 100 μ, 200 μ, and 350 μ diameter) were employed since there was evidence from past tests that the 75 μ particle defined the limiting distance of fallout of interest and the larger sizes best described the pattern wihin this limit. Table 2 presents the falling speeds computed for the 4 sizes. Tables 3, 4, 5, and 6 display the cumulative time of fall from a given altitude for these particle diameters.

TABLE 2.—*Falling speeds as a function of altitude*

[Falling speeds (foot-hour)]

Altitude	75	100	200	350	Altitude	75	100	200	350
0	3,060	5,040	11,700	21,600	65	4,190	7,480	26,100	51,100
5	3,120	5,240	12,300	22,900	70	4,110	7,320	27,600	55,200
10	3,200	5,480	12,900	24,100	75	4,010	7,150	28,100	59,700
15	3,270	5,750	13,700	25,500	80	3,910	6,960	27,800	61,900
20	3,360	5,980	14,400	27,100	85	3,800	6,770	27,100	67,800
25	3,470	6,160	15,300	28,800	90	3,720	6,640	26,500	71,300
30	3,570	6,380	16,300	30,800	95	3,620	6,470	25,800	77,300
35	3,720	6,640	17,500	33,000	100	3,550	6,340	25,300	80,200
40	3,870	6,910	18,600	35,300	105	3,470	6,180	24,800	75,800
45	4,040	7,200	19,800	37,800	110	3,400	6,050	24,000	74,200
50	4,210	7,520	21,400	40,600	115	3,330	5,930	23,700	72,600
55	4,420	7,860	23,200	44,600	120	3,260	5,800	23,400	71,100
60	4,200	7,700	24,400	47,200					

TABLE 3.—*Cumulative time of fall for the 75-μ particles*

[Cumulative time of fall (hours)]

Starting elevation feet 10^{-3}	120 to 115	115 to 110	110 to 105	105 to 100	100 to 95	95 to 90	90 to 85	85 to 80	80 to 75	75 to 70	70 to 65	65 to 60
120 to 115	1.52											
115 to 110	3.01	1.49										
110 to 105	4.46	2.94	1.45									
105 to 100	5.88	4.36	2.87	1.42								
100 to 95	7.27	5.75	4.26	2.81	1.39							
95 to 90	8.63	7.11	5.62	4.17	2.75	1.36						
90 to 85	9.96	8.44	6.95	5.50	4.08	2.69	1.33					
85 to 80	11.26	9.74	8.25	6.80	5.38	3.99	2.63	1.30				
80 to 75	12.52	11.00	9.51	8.06	6.64	5.25	3.89	2.56	1.26			
75 to 70	13.75	12.23	10.74	9.29	7.87	6.48	5.12	3.79	2.49	1.23		
70 to 65	14.95	13.43	11.94	10.49	9.07	7.68	6.32	4.99	3.69	2.43	1.20	
65 to 60	16.14	14.62	13.13	11.68	10.26	8.87	7.51	6.18	4.88	3.62	2.39	1.19
60 to 55	17.30	15.78	14.29	12.84	11.42	10.03	8.67	7.34	6.04	4.78	3.55	2.35
55 to 50	18.46	16.94	15.45	14.00	12.58	11.19	9.83	8.50	7.20	5.94	4.71	3.51
50 to 45	19.67	18.15	16.66	15.21	13.79	12.40	11.04	9.71	8.41	7.15	5.92	4.72
45 to 40	20.93	19.41	17.92	16.47	15.05	13.66	12.30	10.97	9.67	8.41	7.18	5.98
40 to 35	22.25	20.73	19.24	17.79	16.37	14.98	13.62	12.29	10.99	9.73	8.50	7.30
35 to 30	23.62	22.10	20.61	19.16	17.74	16.35	14.99	13.66	12.36	11.10	9.87	8.67
30 to 25	25.04	23.52	22.03	20.58	19.16	17.77	16.41	15.08	13.78	12.52	11.29	10.09
25 to 20	26.50	24.98	23.49	22.04	20.62	19.23	17.87	16.54	15.24	13.98	12.75	11.55
20 to 15	28.01	26.49	25.00	23.55	22.13	20.74	19.38	18.05	16.75	15.49	14.26	13.06
15 to 10	29.55	28.03	26.54	25.09	23.67	22.28	20.92	19.59	18.29	17.03	15.80	14.60
10 to 5	31.13	29.61	28.12	26.67	25.25	23.86	22.50	21.17	19.87	18.61	17.38	16.18
5 to 0	32.75	31.23	29.74	28.29	26.87	25.48	24.12	22.79	21.49	20.23	19.00	17.80

Starting elevation feet 10^{-3}	60 to 55	55 to 50	50 to 45	45 to 40	40 to 35	35 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to 5	5 to 0
120 to 115												
115 to 110												
110 to 105												
105 to 100												
100 to 95												
95 to 90												
90 to 85												
85 to 80												
80 to 75												
75 to 70												
70 to 65												
65 to 60												
60 to 55	1.16											
55 to 50	2.32	1.16										
50 to 45	3.53	2.37	1.21									
45 to 40	4.79	3.63	2.47	1.26								
40 to 35	6.11	4.95	3.79	2.58	1.32							
35 to 30	7.48	6.32	5.16	3.95	2.69	1.37						
30 to 25	8.90	7.74	6.58	5.37	4.11	2.79	1.42					
25 to 20	10.36	9.20	8.04	6.83	5.57	4.25	2.88	1.46				
20 to 15	11.87	10.71	9.55	8.34	7.08	5.76	4.39	2.97	1.51			
15 to 10	13.41	12.25	11.09	9.88	8.62	7.30	5.93	4.51	3.05	1.54		
10 to 5	14.99	13.83	12.67	11.46	10.20	8.88	7.51	6.09	4.63	3.12	1.58	
5 to 0	16.61	15.45	14.29	13.08	11.82	10.52	9.13	7.71	6.25	4.74	3.20	1.62

TABLE 4.—*Cumulative time of fall for the 100-μ particles*

[Cumulative time of fall (hour)]

Starting elevation feet 10^{-3}	120 to 115	115 to 110	110 to 105	105 to 100	100 to 95	95 to 90	90 to 85	85 to 80	80 to 75	75 to 70	70 to 65	65 to 60
120 to 115	0.85	------	------	------	------	------	------	------	------	------	------	------
115 to 110	1.68	0.83	------	------	------	------	------	------	------	------	------	------
110 to 105	2.50	1.65	0.82	------	------	------	------	------	------	------	------	------
105 to 100	3.30	2.45	1.62	0.80	------	------	------	------	------	------	------	------
100 to 95	4.08	3.23	2.40	1.58	0.78	------	------	------	------	------	------	------
95 to 90	4.84	3.99	3.16	2.34	1.54	0.76	------	------	------	------	------	------
90 to 85	5.58	4.73	3.90	3.08	2.28	1.50	0.74	------	------	------	------	------
85 to 80	6.30	5.46	4.63	3.81	3.01	2.23	1.47	0.73	------	------	------	------
80 to 75	7.02	6.17	5.34	4.52	3.72	2.94	2.18	1.44	0.71	------	------	------
75 to 70	7.71	6.86	6.03	5.21	4.41	3.63	2.87	2.13	1.40	0.69	------	------
70 to 65	8.38	7.53	6.70	5.88	5.08	4.30	3.54	2.80	2.07	1.36	0.67	------
65 to 60	9.04	8.19	7.36	6.54	5.74	4.96	4.20	3.46	2.73	2.02	1.33	0.66
60 to 55	9.68	8.83	8.00	7.18	6.38	5.60	4.84	4.10	3.37	2.66	1.97	1.30
55 to 50	10.33	9.48	8.65	7.83	7.03	6.25	5.49	4.75	4.02	3.31	2.62	1.95
50 to 45	11.01	10.16	9.33	8.51	7.71	6.93	6.17	5.43	4.70	3.99	3.30	2.63
45 to 40	11.72	10.87	10.04	9.22	8.42	7.64	6.88	6.14	5.41	4.70	4.01	3.34
40 to 35	12.46	11.61	10.78	9.96	9.16	8.38	7.62	6.88	6.15	5.44	4.75	4.08
35 to 30	13.24	12.39	11.56	10.74	9.94	9.16	8.40	7.66	6.93	6.22	5.53	4.86
30 to 25	14.03	13.18	12.35	11.53	10.73	9.95	9.19	8.45	7.72	7.01	6.32	5.65
25 to 20	14.85	14.00	13.17	12.35	11.55	10.77	10.01	9.27	8.54	7.83	7.14	6.47
20 to 15	15.70	14.85	14.02	13.20	12.40	11.62	10.86	10.12	9.39	8.68	7.99	7.32
15 to 10	16.59	15.74	14.91	14.09	13.29	12.51	11.75	11.01	10.28	9.57	8.88	8.21
10 to 5	17.52	16.67	15.84	15.02	14.22	13.44	12.68	11.94	11.21	10.50	9.81	9.14
5 to 0	18.49	17.64	16.81	15.99	15.19	14.41	13.65	12.91	12.18	11.47	10.78	10.11

Starting elevation feet 10^{-3}	60 to 55	55 to 50	50 to 45	45 to 40	40 to 35	35 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to 5	5 to 0
120 to 115	------	------	------	------	------	------	------	------	------	------	------	------
115 to 110	------	------	------	------	------	------	------	------	------	------	------	------
110 to 105	------	------	------	------	------	------	------	------	------	------	------	------
105 to 100	------	------	------	------	------	------	------	------	------	------	------	------
100 to 95	------	------	------	------	------	------	------	------	------	------	------	------
95 to 90	------	------	------	------	------	------	------	------	------	------	------	------
90 to 85	------	------	------	------	------	------	------	------	------	------	------	------
85 to 80	------	------	------	------	------	------	------	------	------	------	------	------
80 to 75	------	------	------	------	------	------	------	------	------	------	------	------
75 to 70	------	------	------	------	------	------	------	------	------	------	------	------
70 to 65	------	------	------	------	------	------	------	------	------	------	------	------
65 to 60	------	------	------	------	------	------	------	------	------	------	------	------
60 to 55	0.64	------	------	------	------	------	------	------	------	------	------	------
55 to 50	1.29	0.65	------	------	------	------	------	------	------	------	------	------
50 to 45	1.97	1.33	0.68	------	------	------	------	------	------	------	------	------
45 to 40	2.68	2.04	1.39	0.71	------	------	------	------	------	------	------	------
40 to 35	3.42	2.78	2.13	1.45	0.74	------	------	------	------	------	------	------
35 to 30	4.20	3.56	2.91	2.23	1.52	0.78	------	------	------	------	------	------
30 to 25	4.99	4.35	3.70	3.02	2.31	1.57	0.79	------	------	------	------	------
25 to 20	5.81	5.17	4.52	3.84	3.13	2.39	1.61	0.82	------	------	------	------
20 to 15	6.66	6.02	5.37	4.69	3.98	3.14	2.46	1.67	0.85	------	------	------
15 to 10	7.55	6.91	6.26	5.58	4.87	4.13	3.35	2.56	1.74	0.89	------	------
10 to 5	8.48	7.84	7.19	6.51	5.80	5.06	4.28	3.49	2.67	1.82	0.93	------
5 to 0	9.45	8.81	8.16	7.48	6.77	6.03	5.25	4.46	3.64	2.79	1.90	0.97

TABLE 5.—*Cumulative time of fall for 200-μ particles*

[Cumulative time of fall (hour)]

Starting elevation feet 10^{-3}	120 to 115	115 to 110	110 to 105	105 to 100	100 to 95	95 to 90	90 to 85	85 to 80	80 to 75	75 to 70	70 to 65	65 to 60
120 to 115	0.21											
115 to 110	.42	0.21										
110 to 105	.62	.41	0.20									
105 to 100	.82	.61	.40	0.20								
100 to 95	1.02	.81	.60	.40	.020							
95 to 90	1.21	1.00	.79	.59	.39	0.19						
90 to 85	1.40	1.19	.98	.78	.58	.38	0.19					
85 to 80	1.58	1.37	1.16	.96	.76	.56	.37	0.18				
80 to 75	1.76	1.55	1.34	1.14	.94	.74	.55	.36	0.18			
75 to 70	1.94	1.73	1.52	1.32	1.12	.92	.73	.54	.36	0.18		
70 to 65	2.13	1.92	1.71	1.51	1.31	1.11	.92	.73	.55	.37	0.19	
65 to 60	2.33	2.12	1.91	1.71	1.51	1.31	1.12	.93	.75	.57	.39	0.20
60 to 55	2.54	2.33	2.12	1.92	1.72	1.52	1.33	1.14	.96	.78	.60	.41
55 to 50	2.76	2.55	2.34	2.14	1.94	1.74	1.55	1.36	1.18	1.00	.82	.63
50 to 45	3.00	2.79	2.58	2.38	2.18	1.98	1.79	1.60	1.42	1.24	1.06	.87
45 to 40	3.26	3.05	2.84	2.64	2.44	2.24	2.05	1.86	1.68	1.50	1.32	1.13
40 to 35	3.54	3.33	3.12	2.92	2.72	2.52	2.33	2.14	1.96	1.78	1.60	1.41
35 to 30	3.84	3.63	3.42	3.22	3.02	2.82	2.63	2.44	2.26	2.08	1.90	1.71
30 to 25	4.16	3.95	3.74	3.54	3.34	3.14	2.95	2.76	2.58	2.40	2.22	2.03
25 to 20	4.50	4.29	4.08	3.88	3.68	3.48	3.29	3.10	2.92	2.74	2.56	2.37
20 to 15	4.86	4.65	4.44	4.24	4.04	3.84	3.65	3.46	3.28	3.10	2.92	2.73
15 to 10	5.24	5.03	4.82	4.62	4.42	4.22	4.03	3.84	3.66	3.48	3.30	3.11
10 to 5	5.64	5.43	5.22	5.02	4.82	4.62	4.43	4.24	4.06	3.88	3.70	3.51
5 to 0	6.06	5.85	5.64	5.44	5.24	5.04	4.85	4.66	4.48	4.30	4.12	3.93

Starting elevation feet 10^{-3}	60 to 55	55 to 50	50 to 45	45 to 40	40 to 35	35 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to 5	5 to 0
120 to 115												
115 to 110												
110 to 105												
105 to 100												
100 to 95												
95 to 90												
90 to 85												
85 to 80												
80 to 75												
75 to 70												
70 to 65												
65 to 60												
60 to 55	0.21											
55 to 50	.43	0.22										
50 to 45	.67	.46	0.24									
45 to 40	.93	.72	.50	0.26								
40 to 35	1.21	1.00	.78	.54	0.28							
35 to 30	1.51	1.30	1.08	.84	.58	0.30						
30 to 25	1.83	1.62	1.40	1.16	.90	.62	0.32					
25 to 20	2.17	1.96	1.74	1.50	1.24	.96	.66	0.34				
20 to 15	2.53	2.32	2.10	1.86	1.60	1.32	1.02	.70	0.36			
15 to 10	2.91	2.70	2.48	2.24	1.98	1.70	1.40	1.08	.74	0.38		
10 to 5	3.31	3.10	2.88	2.64	2.38	2.10	1.80	1.48	1.14	.78	0.40	
5 to 0	3.73	3.52	3.30	3.06	2.80	2.52	2.22	1.90	1.56	1.20	.82	0.42

TABLE 6.—*Cumulative time of fall for 350-μ particles*

[Cumulative time of fall (hours)]

Starting elevation feet 10^{-3}	120 to 115	115 to 110	110 to 105	105 to 100	100 to 95	95 to 90	90 to 85	85 to 80	80 to 75	75 to 70	70 to 65	65 to 60
120 to 115	0.07	------	------	------	------	------	------	------	------	------	------	------
115 to 110	.14	0.07	------	------	------	------	------	------	------	------	------	------
110 to 105	.21	.14	0.07	------	------	------	------	------	------	------	------	------
105 to 100	.27	.20	.13	0.06	------	------	------	------	------	------	------	------
100 to 95	.33	.26	.19	.12	0.06	------	------	------	------	------	------	------
95 to 90	.40	.33	.26	.19	.13	.07	------	------	------	------	------	------
90 to 85	.47	.40	.33	.26	.20	.14	0.07	------	------	------	------	------
85 to 80	.55	.48	.41	.34	.28	.22	.15	0.08	------	------	------	------
80 to 75	.63	.56	.49	.42	.36	.30	.23	.16	0.08	------	------	------
75 to 70	.72	.65	.58	.51	.45	.39	.32	.25	.17	0.09	------	------
70 to 65	.81	.74	.67	.60	.54	.48	.41	.34	.26	.18	0.09	------
65 to 60	.91	.84	.77	.70	.64	.58	.51	.44	.36	.28	.19	0.10
60 to 55	1.02	.95	.88	.81	.75	.69	.62	.55	.47	.39	.30	.21
55 to 50	1.14	1.07	1.00	.93	.87	.81	.74	.67	.59	.51	.42	.33
50 to 45	1.27	1.20	1.13	1.06	1.00	.94	.87	.80	.72	.64	.55	.46
45 to 40	1.41	1.34	1.27	1.20	1.14	1.08	1.01	.94	.86	.78	.69	.60
40 to 35	1.56	1.49	1.42	1.35	1.29	1.23	1.16	1.09	1.01	.93	.44	.75
35 to 30	1.72	1.65	1.58	1.51	1.45	1.39	1.32	1.25	1.17	1.09	1.00	.91
30 to 25	1.89	1.82	1.75	1.68	1.62	1.56	1.49	1.42	1.34	1.26	1.17	1.08
25 to 20	2.07	2.00	1.93	1.86	1.80	1.74	1.67	1.60	1.52	1.44	1.35	1.26
20 to 15	2.26	2.19	2.12	2.05	1.99	1.93	1.86	1.79	1.71	1.63	1.54	1.45
15 to 10	2.46	2.39	2.32	2.25	2.19	2.13	2.06	1.99	1.91	1.83	1.74	1.65
10 to 5	2.67	2.60	2.53	2.46	2.40	2.34	2.27	2.20	2.12	2.04	1.95	1.86
5 to 0	2.89	2.82	2.75	2.68	2.62	2.56	2.49	2.42	2.34	2.26	2.17	2.08

Starting elevation feet 10^{-3}	60 to 55	55 to 50	50 to 45	45 to 40	40 to 35	35 to 30	30 to 25	25 to 20	20 to 15	15 to 10	10 to 5	5 to 0
120 to 115	------	------	------	------	------	------	------	------	------	------	------	------
115 to 110	------	------	------	------	------	------	------	------	------	------	------	------
110 to 105	------	------	------	------	------	------	------	------	------	------	------	------
105 to 100	------	------	------	------	------	------	------	------	------	------	------	------
100 to 95	------	------	------	------	------	------	------	------	------	------	------	------
95 to 90	------	------	------	------	------	------	------	------	------	------	------	------
90 to 85	------	------	------	------	------	------	------	------	------	------	------	------
85 to 80	------	------	------	------	------	------	------	------	------	------	------	------
80 to 75	------	------	------	------	------	------	------	------	------	------	------	------
75 to 70	------	------	------	------	------	------	------	------	------	------	------	------
70 to 65	------	------	------	------	------	------	------	------	------	------	------	------
65 to 60	------	------	------	------	------	------	------	------	------	------	------	------
60 to 55	0.11	------	------	------	------	------	------	------	------	------	------	------
55 to 50	.23	0.12	------	------	------	------	------	------	------	------	------	------
50 to 45	.36	.25	0.13	------	------	------	------	------	------	------	------	------
45 to 40	.50	.39	.27	0.14	------	------	------	------	------	------	------	------
40 to 35	.65	.54	.42	.29	0.15	------	------	------	------	------	------	------
35 to 30	.81	.70	.58	.45	.31	0.16	------	------	------	------	------	------
30 to 25	.98	.87	.75	.62	.48	.33	0.17	------	------	------	------	------
25 to 20	1.16	1.05	.93	.80	.66	.51	.35	0.18	------	------	------	------
20 to 15	1.35	1.24	1.12	.99	.85	.70	.54	.37	0.19	------	------	------
15 to 10	1.55	1.44	1.32	1.19	1.05	.90	.74	.57	.39	0.20	------	------
10 to 5	1.76	1.65	1.53	1.40	1.26	1.11	.95	.78	.60	.41	0.21	------
5 to 0	1.98	1.87	1.75	1.62	1.48	1.33	1.17	1.00	.82	.63	.43	0.22

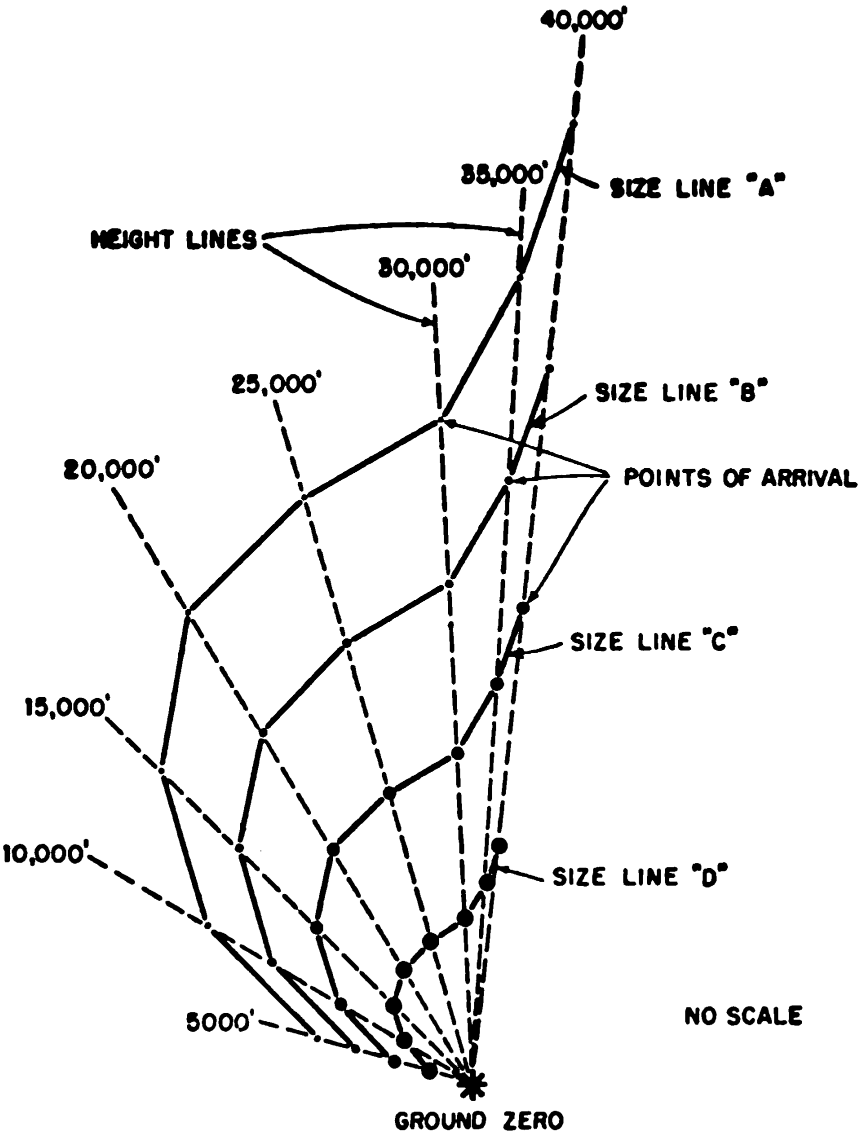
2.1.5.6 Meteorological procedures

It is necessary to have available the best possible description of the winds aloft to determine the arrival points of particles of various sizes originating at various altitudes. Such data are usually available from the normal upper air soundings routinely taken by Weather Bureau and military meteorological stations. Although wind velocity as a function of height varies continuously, it can be described by an average speed and direction in discrete layers. Such averaging can best be obtained from the WBAN–20 form where the original data are recorded. The technique employed in this report was to divide the atmosphere into layers 5,000 feet thick and determine an average speed and direction for each layer. When the average falling speed of particles through these 5,000-foot layers and the speed and direction of the wind are known, horizontal displacement can be computed. Thus for each particle size a vector may be drawn for the average particle displacement in a particular 5,000-foot layer. Addition of such vectors from all layers describes the trajectory projection of a particle of given size. Similar plotting for all particle sizes originating at all elevations within the cloud source will map the fallout on the earth's surface.

This technique is valid for any atmosphere that has negligible vertical motion and is in a steady state condition with respect to the horizontal winds during the time needed for the slowest particle to fall from the highest altitude to the ground. Such an assumption is not realistic for situations arising from many of the megaton devices because 15 to 20 hours are necessary to establish the fallout area. Consequently, when computing particle trajectories, an attempt should be made to consider how the wind varies with time, how it varies with distance from ground zero, what effect vertical motions have on particle falling speeds, and how they vary with space and time. Such considerations complicate computation of trajectories extremely. In most cases valid input data describing these variables are not available. This phase of the problem is discussed below.

2.2 Plotting technique

The use of "particle size" and "height" lines in mapping fallout is a standard technique employed by most analytical methods. This technique simply describes a grid (fig. 9) on the earth's surface indicating where fallout particles of certain sizes will arrive and from what altitude they came. These parameters are the basic data for describing the fallout pattern.



NOTE: Four particle sizes originating at altitudes up to 40,000 feet in a hypothetical wind field

FIGURE 9.—Basic Fallout Plot Showing Grid of Size Lines and Height Lines.

Assuming steady state meteorological conditions without vertical motion or space variation of the winds, it is very easy to construct a grid describing arrival points on the earth's surface for particles of various sizes originating at different altitudes. This grid is constructed by ignoring the horizontal distribution of particles in the cloud model and by plotting those trajectories that originate along the line source describing the vertical axis of the cloud.

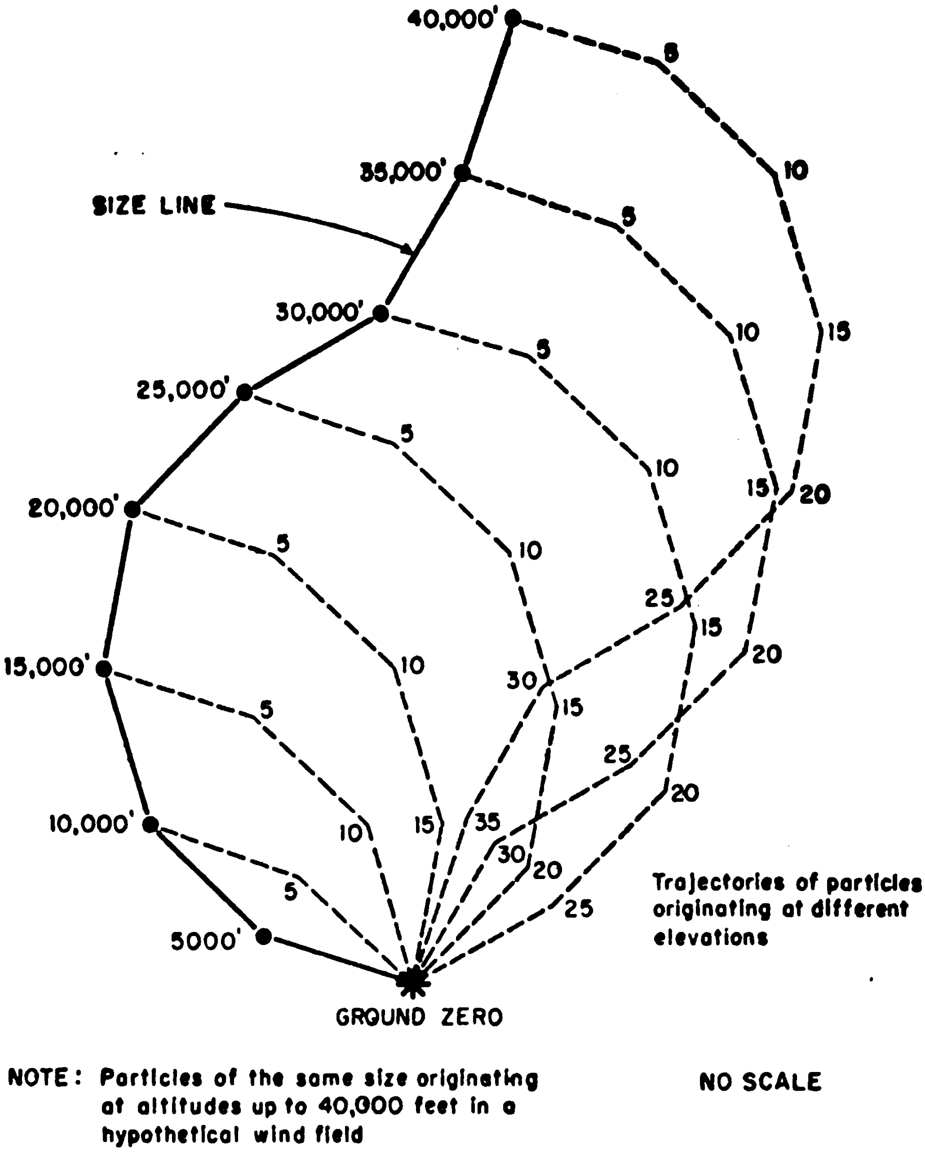


FIGURE 10.—Comparison of plotting techniques either by use of trajectories or by use of a size line.

Plotting trajectories for each particle size at every starting elevation is the first step in determining the resultant fallout pattern; however, the drafting involved is tedious and time consuming. This effort can be reduced greatly by plotting from the ground up, as is done in the construction of a wind hodograph. Such a plot is made by starting at ground zero and working up through the altitude increments to the desired elevation. Although this technique does not plot the trajectory of the particle, it does define the arrival points on the surface of the earth of particles starting at each altitude increment (Fig. 10). To plot these size lines one must make the preliminary computations of particle falling times through each altitude increment to obtain the displacement for various wind velocities as described earlier in section 2.1.5.5.

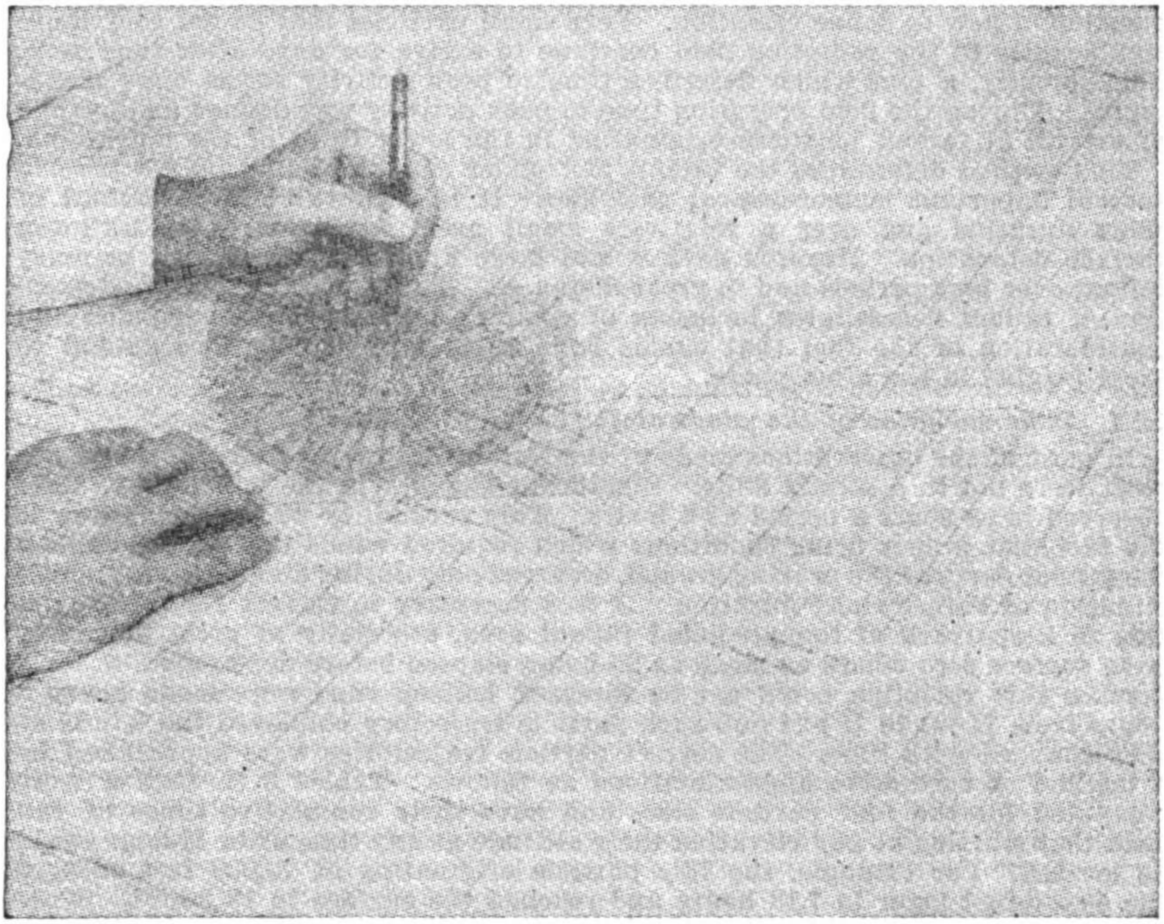


FIGURE 11.—Fallout plotting device.

A plotting device (fig. 11) has been described elsewhere[8] which facilitates the computations required for the size lines of the fallout pattern. Such devices were constructed for 4 particle sizes: 75, 100, 200, and 350 μ in diameter. With these plotters trajectories or size lines can be plotted from any elevation to 120,000 feet for the 4 particle sizes. The plotters automatically account for the variable particle falling speed. They also eliminate the need for drafting equipment. After establishing the particle arrival points by either the use of size lines or trajectories, height lines can be constructed. These lines joining surface zero with the arrival points of all particles from the same elevation are most descriptive for they define the path along which all particle sizes will deposit from that originating altitude.

The height lines describing the fallout from the lower portion of the mushroom immediately establish the "hot line." The "hot line" is best defined as that portion of the fallout area wherein the highest levels of activity are found relative to the adjacent areas. Under most meteorological conditions this area is described by a line from surface zero that coincides with the height lines from the altitude layers that include the base of the mushroom; for the source model was so defined to concentrate the activity in this volume.

Since the plotted grid of size lines and height lines was based on a line source of activity each particle point must be expanded to the appropriate cloud or stem diameter from which it originated. This expansion, after taking into consideration the radial particle size fractionation in the source model, defines the perimeter of the area. One then has a map indicating the fallout area and the path of expected highest activity.

Curves of time of arrival of fallout through the pattern are established by simply assigning the appropriate value of falling time to each expanded circle about the arrival points and by constructing from this network of values isotime contours that indicate the earliest time at which fallout will arrive at a given distance from the shot point. The determination of the time of cessation of fallout at any location may be plotted similarly, however, one is faced with the

[8] E. A. Schuert, A Fallout Plotting Device, USNRDL Technical Rept. 127, February 1957.

question of how to define cessation. Very small particles that do not contribute significantly to the radiation field continue to arrive for days after time zero. Consequently, a plot which describes time to peak activity seems more meaningful. During the field operation time to peak activity was defined as the time of arrival of fallout particles originating in the lower third of the mushroom.

This method determines the fallout plot under conditions that do not involve several important meteorological variables. It is most valid for a fallout of short duration and over a relatively small area, for example, a 1-kiloton surface detonation. Megaton devices and large kiloton yields deposit primary fallout over long periods and to great distances. To map such extensive deposition of fallout necessitates inclusion of complex meteorological variables and consideration of the fact that clouds from these large detonations extend to great heights in the atmosphere.

2.2.1 Time variation of the winds aloft

In most of the observations made at the Eniwetok Proving Ground, the winds aloft were not in a steady state. Significant changes in the winds aloft were observed in as short a period as 3 hours. This variability was probably due to the fact that proper firing conditions which required winds that would deposit the fallout north of the proving ground, occurred only during an unstable synoptic situation of rather short duration. It was necessary to correct for this variation to keep track of the predicted fallout area, especially at great distances from surface zero where as much as 20 hours elapsed before deposition.

Since this variation could not be forecast, balloon runs were made every 3 hours from H+O to H+24 and each particle trajectory employed the winds as they changed with time. The correct particle trajectories were approached by a method of successive approximations as follows: Tables 3 through 6 were computed for the four particle sizes and gave their cumulative times of fall such that starting at any elevation their altitude at any time after H-hour could be located. For example, the 75-μ particle originating at 70,000 feet entered the 40,000-foot layer in 7.18 hours and reached the surface in 19 hours. Since new upper air observations were obtained every 3 hours it was assumed that the balloon released at H+O represented the winds aloft until H+3 hours and the balloon released at H+3 hours represented the winds until H+6 hours and so on. Therefore, as the particle settled to earth the appropriate winds aloft were applied to it.

The first step was to plot size lines for the particles based on the H+O hour winds. This established a fallout plot that assumed the winds would not change with time. When the H+3 winds became available a similar plot was made based on them. With the aid of tables 3 through 6 the particles starting at various elevations were located in altitude at H+3. These H+3 hour points are marked at the proper altitude on each size line. The two size lines, H+O and H+3 are then overlayed such that the H+3 hour points are coincident and the combined size lines determined with the aid of a light table. This is done by taking the upper portion of the H+O hour size line and the lower portion of the H+3 size line. This first approximation then assumes that the H+3 hour winds will remain steady for the remainder of the particles flight. The process is repeated using the combined size line and the new size line for the next set of wind data until the particle reaches the surface. Therefore for each new wind observation a closer approximation of the corrected time variable plot is made until ultimately the plot is quantitative.

2.2.2 Space variation

The preceding computations assumed that the winds aloft as measured at the point of detonation at a given time are the same throughout the area for that time. Since the fallout can deposit hundreds of miles from surface zero, ideally, one would like winds-aloft measurements throughout the volume traversed by the particles. Correction for space variation of the winds is then necessary, however, in most cases not as significant as is time variation. Most weather networks are not refined enough to allow quantitative correction for these errors.

2.2.3 Vertical motions

In applying particle falling speeds to the forecasting technique, it is assumed that the atmosphere has no vertical velocity. Computations made at the Eniwetok Proving Ground[a] to 50,000 feet indicated that large cellular vertical

[a] Under the direction of Comdr. Daniel F. Rex, Joint Task Force Seven Meteorological Center, Pearl Harbor, T. H.

motions in the atmosphere sometimes attained speeds equal to and greater than the settling speed of a 75-μ particle. A time-space correction should be made to the falling speeds of the particles to compensate for this parameter. However, in the work at the test site it was not possible to include this effect in the fallout forecasts. Certain anomalies discussed below may be due to such an effect and postshot analysis is being conducted to see whether they are resolved when the vertical motions have been taken into account.

3. DISCUSSION OF FIELD TEST RESULTS

The forecasting technique described was employed by the fallout program at the Eniwetok Proving Ground to satisfy certain project requirements. One project had three ships equipped to collect fallout and their positions had to be determined for most efficient collection; another sampled the ocean for fallout; while another made an aerial survey of the contaminated area. The navigational schedules for these latter projects were based on the forecast fallout pattern. Operations were controlled through the program control center aboard the task force command ship where the forecasts were prepared.

The meteorological data was received from the weather ship at Bikini Atoll as well as from weather stations at Rongerik Atoll and Eniwetok Atoll. Furthermore all forecasts made by the task force weather central at Eniwetok Atoll were usually available aboard the command ship by facsimile through the ships weather station.

Upper air measurements were made at Bikini, Rongerik, and Eniwetok Atolls every 3 hours starting at H—24 hour and continuing until H+24 hour for any given detonation. The frequency of observations was usually increased during the period from H—6 to H—2 hours. The altitudes reached on the wind runs were remarkably high and gave perhaps the best set of winds-aloft measurements to date. The average termination altitude was approximately 90,000 feet with many runs over 100,000 feet. Such excellent coverage of the winds aloft was a major help in the fallout forecasting.

Fallout forecasts were made every 3 hours starting at H—24 hour using the *measured* winds available at the time. This process was continued up to shot time and from then on the technique of correcting for time variation was employed every 3 hours until the fallout event was completed. It was not feasible to correct for space variation and vertical motions during this period because of lack of time and data.

3.1 Fallout plots

The fallout forecasts determined at the weapons-test operation were based entirely on measured data and quantitatively considered time variation of the wind. No space variation corrections or computed values of vertical motions were employed in their construction.

The area of measured fallout from shot A is compared with the forecast fallout plot in figure 12. Figures 13, 14, and 15 are similar comparisons for shots B, C, and D. Although C and D were water-surface shots, it is evident that the forecasting technique succeeded in representing the measured fallout area as well as it did for the land-surface detonations, A and B.

The comparison is excellent for all shots except B and as yet the discrepancy betwen the forecast fallout area and that which was measured is unknown. There is some indication that consideration of vertical motions will have to be made for shot B during the time of fallout since computed vertical motions were significant in magnitude. Such analysis including space variation is being carried out at this time for all four detonations and the refined data will be published later.

4. SUMMARY

The fallout forecasting technique described in this report was successfully employed for both land surface and water surface detonations at the Eniwetok Proving Ground. With known meterological data such a technique will successfully qualify the area of fallout and indicate qualitatively the relative intensity of radiation.

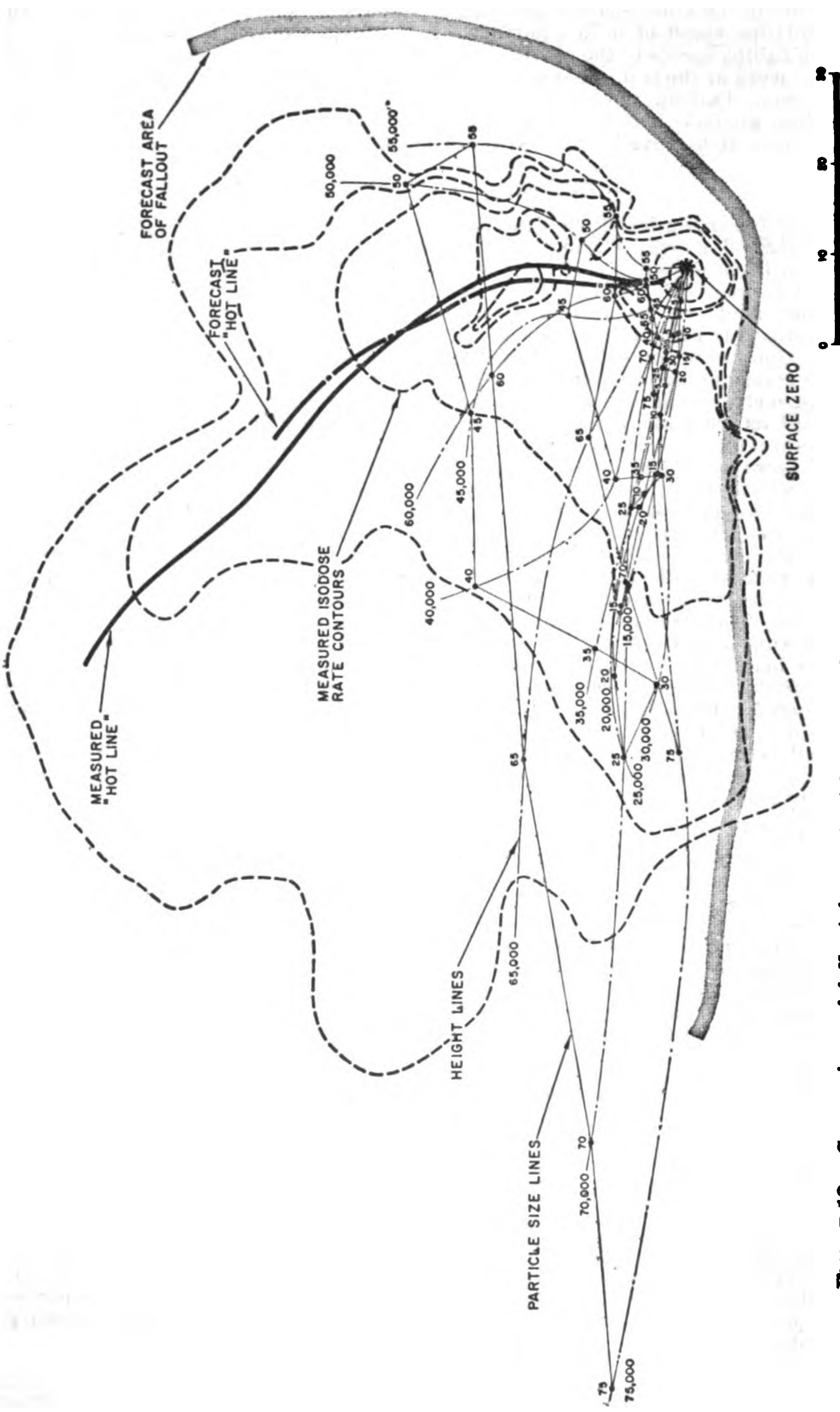


FIGURE 12.—*Comparison of fallout forecast with test results—shot A*

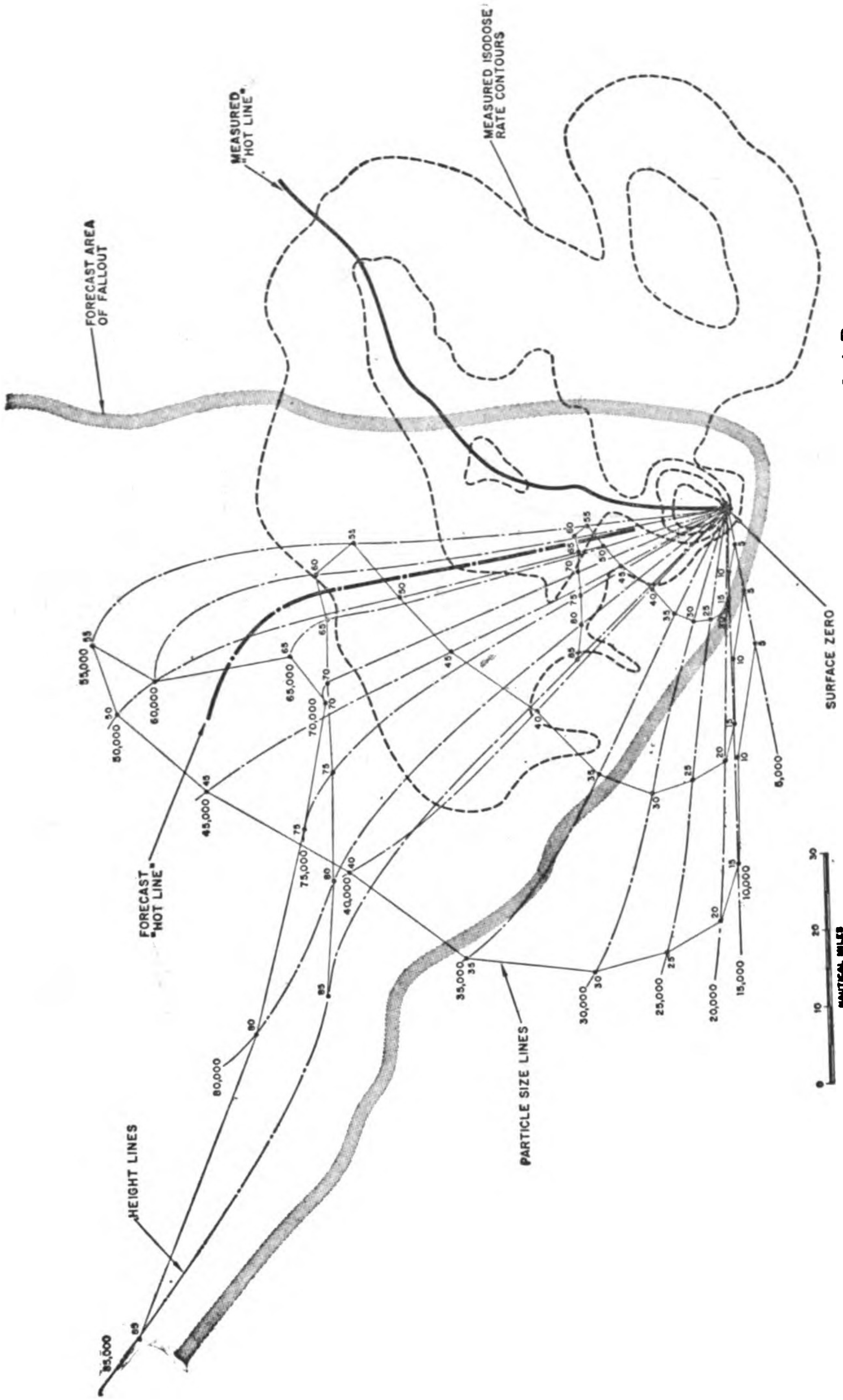


FIGURE 13.—*Comparison of fallout forecast with test results—shot B.*

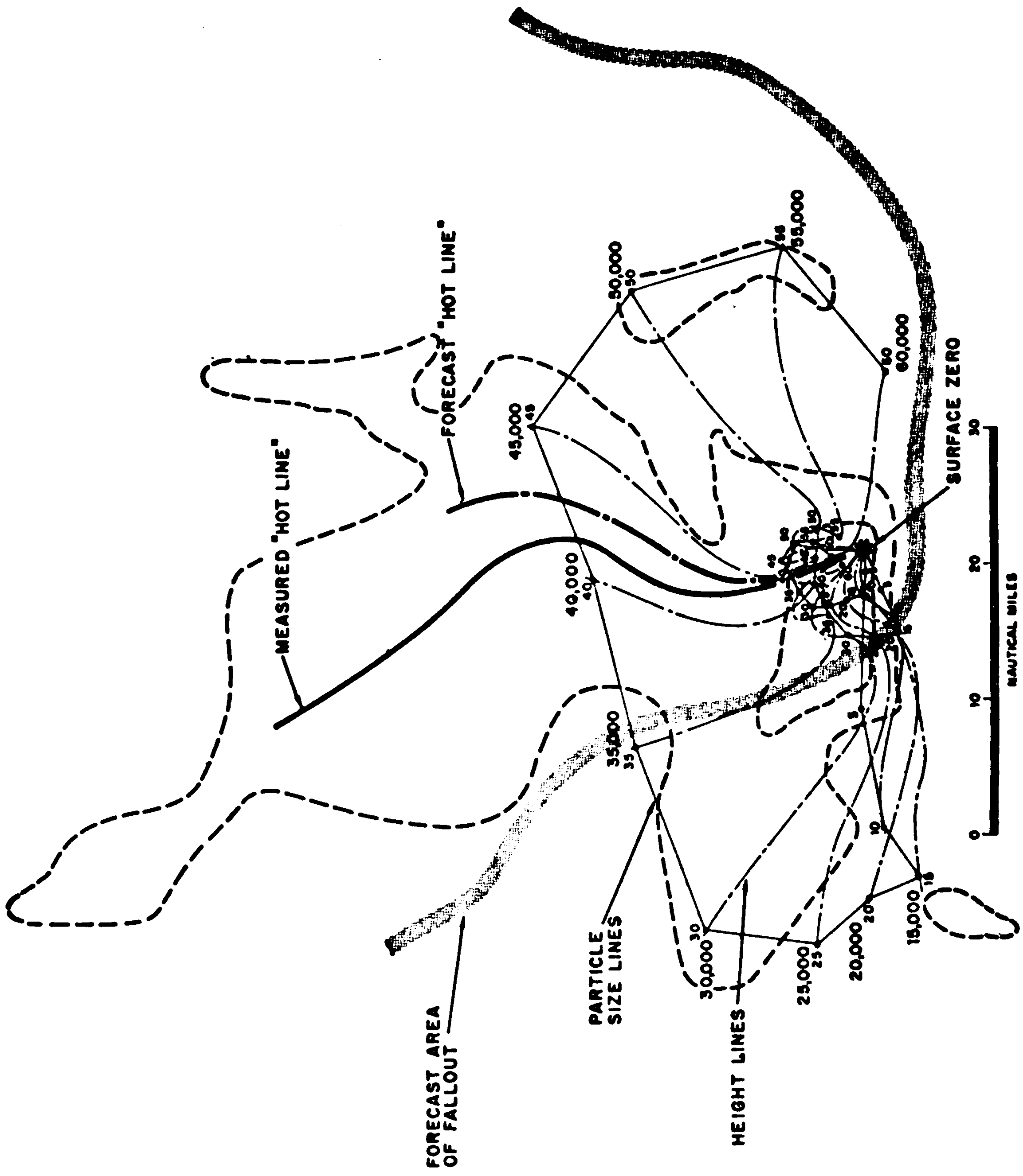


FIGURE 14.—*Comparison of fallout forecast with test results—shot C.*

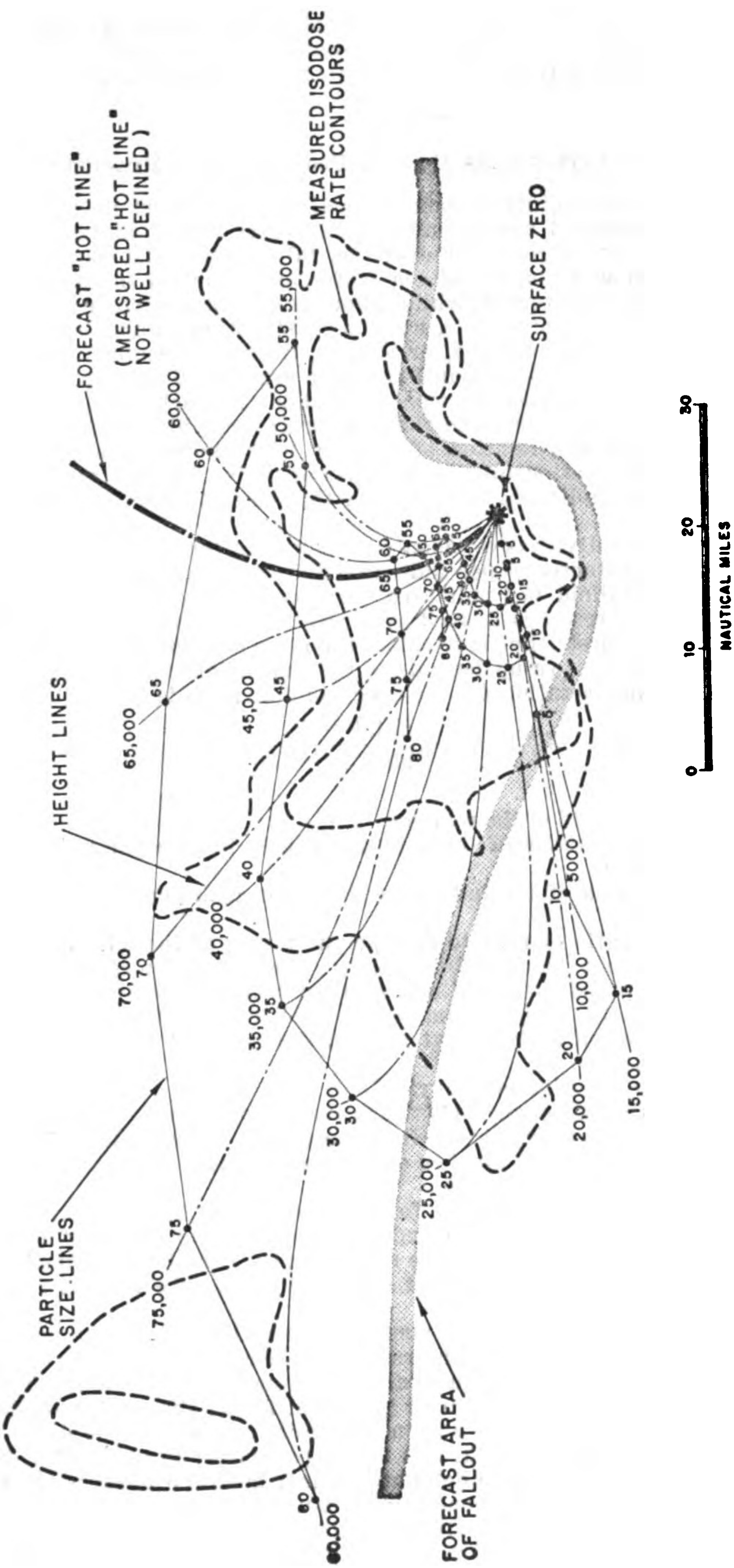


FIGURE 15.—*Comparison of fallout forecast with test results—shot D.*

Precise determination of the fallout area requires consideration of many complex meteorological parameters. However from the above analysis a practical field tool can be developed that in most cases will satisfactorily define the area of interest.

Mass Activity Relationships Derived From Fallout Measurements

Since fallout consists mainly of nonradioactive debris from nuclear detonations, the essential physical and chemical behavior of fallout is determined by the nature of the inert debris. For example, fallout from detonations on the surface of the ocean will consist of sea water, construction materials of the weapon, and radioactive materials, while fallout from a land-surface burst is produced from soil and target materials, weapon-construction materials, and radioactive elements. In terms of mass, or weight, the relative abundance of the radioactive elements is much less than 1 part in a million. Therefore, except for their radioactive properties, these elements would be extremely difficult to detect.

Accordingly, all major physical and chemical processes which deal with fallout require information on the relation of activity with the other bulk material. The simplest of these relationships is the ratio of activity to the gross mass or its inverse. A more complicated one would be the relation of activity to particle size.

In the fallout area, activity is commonly measured in terms of r/hr, and since r/hr is proportional to activity per unit area the equivalent mass quantity is, therefore, weight of fallout per unit area. For convenience in other computations, the relation of interest is defined as a ratio of mass per unit area to r/hr at a given time after burst; thus it is called the mass contour ratio and is given the symbol $M_r(t)$, since its value depends on the time after burst (due to decay). The generalized scaling equation for the mass contour ratio is

$$M_r^\lambda(t) = \frac{f \cdot K A_\lambda W^{(a-1)}}{bR(t)[a_{FP}(t) + a_I(t)]} \qquad (1)$$

in which

1. W is the total yield of the weapon.
2. $a_{FP}(t)$ is the activity of the fission products in d/m per unit area for 10^6 fissions at time, t.
3. $a_I(t)$ is the sum of the induced activities in d/m per unit area for 10^6 fissions at time, t.
4. R(t) is the ratio of r/hr to d/m per unit area at time, t. If the ratio is computed for an ideal infinite plane, then $R(t)=uR_0(t)$ in which $R_0(t)$ is the computed ratio and u is a factor which accounts for the effect of the terrain on the radiation intensity; knowledge of the photon spectra of the FP + induced activities at time, t, are required to make a reliable calculation of $R_0(t)$.
5. b is the ratio of fission to total yield.
6. bW is then the fission yield (W^{-1} is in the numerator).
7. K is a conversion factor relating the choice of units for W (lbs. of TNT, KT, MT, etc.) to the number of fissions per unit of fission yield, and the units of area and mass desired.
8. $A\lambda W^a$ is the scaling relation for the mass of material removed from the crater. The constant $A\lambda$ depends on the height or depth of burst; it is usually given as a function of the scaled depth, λ, and λ is defined as the depth or height of the burst in feet divided by the cube root of the yield in equivalent lbs. of TNT.
9. f is the fraction of the total mass of material which is thrown out of the crater and gets mixed with the radioactive elements.

The equation constants have been evaluated from available data. The dependence of $A\lambda$ on λ is usually given in graphical form; the results of its use with available data is satisfactory within the limits of error of the data. The mass contour ratio, defined by Eq. 1, is a major parameter in evaluating decontamination results for fallout from detonations near land and harbors; it is also used to convert results from one condition of burst to another.

For high yield detonations, the relation holds, within a given error, up to within the heavy blast damage region; for smaller yields, and under ground bursts where large crater lips are formed and much inactive soil and debris are thrown randomly about, no given relation holds.

RELATION OF RADIOACTIVE DECAY TO COUNTERMEASURES

The fundamental concepts of a time-phased countermeasure system are based on the fact that the radiation intensity decreases with time. The time-history of the radiation intensity at some location in the fallout area starts wher fallout arrives; the intensity increases or "builds up" to a peak sometime during fallout and then decreases when the decay rate is more rapid than the rate of arrival of fallout. After fallout ceases, the radiation intensity decreases with a rate determined by the half-lives and relative abundances of the radionuclides present in the fallout.

Knowledge of the shape of the radiation intensity time-history curve is required to determine what countermeasures can be used at different times after attack and what their requirements are. Mathematically, the areas under the time-history curve for various time periods give estimates of the radiation dosages that could be received during those periods without countermeasures.

In the early period, when the radiation intensity is rapidly increasing toward the peak, large dosages can be received in a very short time; therefore, in areas where the peak is higher than some given value, all personnel exposed to the radiation (for a given time) will become casualties. If these personnel are protected from radiation during this period, they will be able to perform their functions at a later time.

After the intensity decreases (due to decay), certain short-time controlled tasks can be performed in the open without risk of casualties.

The major short-time task is the reclamation of vital operations by decontamination or other actions which will reduce the dose to personnel over a subsequent period to an acceptable amount.

After a longer period of time only the very long-lived radionuclides remain. In fission products alone, the majority of these nuclides are beta emitters. Thus when the gamma emitters have decayed beyond a certain level as to be of no hazard to personnel, the only countermeasures required will be those that deal with ingestion of long-lived beta emitting nuclides.

Again, the guide for determining the appropriate time(s) of application of a given countermeasure(s), what the performance specifications should be, and how the operational application should be made all depend upon the degree of knowledge of the radiation intensity time-history curve—i .e. range of absolute magnitude of the intensities, areas involved for different yields, etc.

The dosage, or area under the intensity-time curve, is sensitive to the shape of the curve. One commonly used decay curve for estimating dosage is that described by the $t^{-1.2}$ function. Since this function is known to be only an approproximation, it is of interest to know to what degree it represents—or misrepresents—the true nature of the intensity-time curve; and, specifically, to what degree the dose estimates from its use differs from other theoretical curves which have given intensity-time curves similar to those observed experimentally. Integrated doses for various periods of possible exposure (stay times) at a series of entry times for a standard intensity of 1,000 r/hr (at $H+1$ hr) are given in table 1 for both the $t^{-1.2}$ function and a normal decay (for radioactivity from a hypothetical weapon in which the decay curve is a normalized average from a number of experimental decay curves) titled "Theoretical Decay" in the table. It may be noted that the intensity for the theoretical decay is higher than for the $t^{-1.2}$ until between 1 and 2 months after burst; after this time, the theoretical decay curve is lower.

The differences in dose between the two for different stay times is given in table 2; a generalizing of the tabulation is that the $t^{-1.2}$ function underestimates the dose for early entry and short stay time and overestimates the dose for late entry and long stay times. The magnitude and order in which the differences occur are considered to be operationally significant for planning purposes; therefore the $t^{-1.2}$ function is no longer used by the Military Evaluations Group of NRDL in its countermeasure evaluations investigations for military sponsors.

TABLE 1.—*Accumulated doses (r) for various exposure periods in a field of 1,000 r/hr at 1 hr after burst*

Entry time	Intensity at entry time		Exposure period							
	$t^{-1.2}$ law (r/hr)	Theoretical decay (r/hr)	1 day (r)	1 week (r)	1 month (r)	6 months (r)	1 year (r)	3 years (r)	5 years (r)	10 years (r)
1 day	22	29.2	342	901	1,320	1,720	1,840	1,990	2,060	2,140
				1,499	2,000	2,355	2,414	2,437	2,439	2,441
2 days	9.6	16.2	180	599	983	1,375	1,495	1,650	1,715	1,795
				1,046	1,504	1,849	1,908	1,931	1,933	1,935
1 week	2.13	3.76	47.5	232	509	865	985	1,141	1,204	1,275
				325	633	943	999	1,022	1,024	1,026
2 weeks	.95	1.13	21.5	121.5	322	642	755	912	972	1,052
				137	354	621	675	697	699	701
1 month	.371	.404	9	55	175	435	540	690	753	830
				59	171	384	427	448	450	452
2 months	.162	.150	5	26.9	91	290	378	525	595	671
				27	82	225	259	278	280	282
6 months	.044	.032	2	7.4	29.8	124	192.5	312	368	455
				4	19	60	73	84	86	88
1 year	.019	.00575	1	3.2	13.5	64.7	108.5	203	256	315
				1	4	13	20	24	26	28
1½ year	.0114	.00206		1.9	8	42	73.5	149	189	252
				.4	1.5	7	9	11	13	15
2 years	.008	.000985		1.3	5.7	30.8	54.4	117	156	215
				.2	.7	3.4	4.9	7.5	9	11
4 years	.0035			.6	2.5	14.4	27.5	67.1	94.5	140
	.0015			.25	1.2	6.5	12.8	34	50.8	82.2

TABLE 2

Error Chart for Difference in Dose Between Use of $t^{-1.2}$ and A Standard Decay Curve
(values in percent difference in dose)

Entry Time		Stay Time 1 wk	2 wk	3 wk	1 mo.	2 mo	3 mo	6 mo	9 mo	1 yr	2 yr	3 yr	5 yr	10 yr	
1 day		+65	+59	+55	+51	+47	+42	+37	+34	+31	+25	+22	+18	+14	+10%
2 days		+75	+63	+57	+53	+59	+41	+34	+28	+27	+21	+17	+13	+8	
3 days		+74	+59	+53	+47	+40	+35	+29	+29	+21	+14	+10	+6	+1	
4 days	>50	+68	+53	+47	+42	+34	+29	+23	+19	+16	+8	+4	-	-6	-10%
5 days		+62	+45	+39	+36	+28	+23	+18	+13	+10	+2	-2	-7	-13	
6 days	+50	+53	+40	+34	+31	+24	+21	+13	+10	+6	-2	-6	-11	-18	-20%
7 days		+40	+30	+28	+24	+18	+14	+9	+4	+2	-7	-12	-17	-24	
8 days		+34	+26	+24	+21	+16	+11	+6	+2	-1	-10	-15	-21	-30	
9 days	+20	+26	+21	+19	+17	+12	+8	+3	-1	-4	-13	-19	-26	-35	
10 days		+18	+18	+16	+14	+9	+5	+1	-3	-7	-17	-25	-30	-40	
11 days	+10	+17	+15	+14	+13	+8	+4	-	-4	-8	-19	-25	-32	-42	
12 days	+10	+10	+8	+9	+8	+5	+1	-3	-7	-11	-22	-29	-37	-47	
13 days		+13	+13	+12	+11	+3	+2	-3	-7	-11	-23	-29	-37	-48	
2 weeks		+13	+14	+12	+10	+6	+2	-3	-8	-12	-23	-31	-39	-50	-50%
3 weeks	+10	+16	+11	+11	+7	+2	-2	-8	-13	-18	-32	-41	-52	-65	
4 weeks		+5	+3	+3	-	-4	-6	-12	-19	-25	-43	-52	-65	-80	
1 month	+10	+7	+5	+4	-2	-4	-8	-13	-20	-26	-43	-54	-67	-84	
5 weeks		+6	+1	-2	-5	-11	-13	-17	-26	-32	-53	-64	-77	-93	-100%
6 weeks		-	-7	-7	-8	-18	-6	-23	-34	-37	-64	-74	-91	-112	
2 months		-	+2	-8	-11	-12	-17	-29	-39	-46	-71	-89	-106	-138	
9 weeks	-10	-18	-15	-18	-22	-21	-28	-34	-44	-53	-79	-93	-118	-142	
3 months	-20	-8	-15	-18	-17	-20	-24	-37	-52	-66	-99	-118	-150	-186	-200%
4 months	-50	-20	-25	-43	-35	-31	-39	-62	-79	-97	-140	-166	-198	-240	
6 months	-100	-75	-100	-90	-58	-71	-74	-109	-140	-163	-230	-275	-325	-415	
9 months	-200	-125													
1 year		-200													

Physical Chemistry of Fallout as It Relates to Decontamination Countermeasures

GENERAL BACKGROUND

In countermeasures, the basic physical chemistry of fallout is concerned with the interactions of fallout with surfaces. These interactions are then related, in a practical sense, to an appropriate choice of reclamation procedures. Further, an understanding of the chemistry leads to a precise concept of the nature of fallout and to the significant properties of both the weapon and the target that combine to produce fallout of a given chemical nature as well as the implication of these properties on the countermeasure performance.

In radiological defense designed for nuclear attack there are three basic kinds of fallout of interest: (1) From detonations at sea, (2) from detonations on land, and (3) from detonations on harbor targets. The general description of the interactions of these kinds of fallout will aid in explaining some of the technical problems; some of the experimental data and techniques are also applicable to reclamation problems which might range from a laboratory spill of a small amount of activity to a reactor accident although none of these would ever approach the scope of the reclamation task envisioned in event of fallout from nuclear attack.

SEAWATER FALLOUT

Seawater fallout will consist of seawater, bomb structural and target materials, and radioactive products. The bulk of the material thrown up in a detonation at sea will be seawater of which about 3 percent of the weight is salt (mainly sodium chloride); the radioactive elements will be present at concentrations less than 1 part in a million. A high yield explosion will throw this material to such altitudes that much of the water can evaporate in falling back to earth; with lower yield explosions less will evporate. Depending on the humidity, in one extreme the fallout might arrive as wet, saturated salt particles and in the other as water droplets much like rain.

When these droplets or pseudo crystalline salt particles strike a surface (for simplicity, assume an impervious surface such as painted metal or wood) they will tend to stick where they land, and since fine mistlike particles travel almost horizontally more of them can strike and stick on vertical surfaces. Larger water droplets, however, when deposited in large numbers will fall more vertically and run off vertical surfaces.

Since the bulk material (salt) is water soluble and never completely dries out (or stays dried out) in the presence of water vapor in the atmosphere, the radioactive as well as the salt atoms (ions and colloids) can move about in water and diffuse toward the surface. Within several hours after deposition, the droplets will all evaporate to the same degree under the same conditions and reach the same equilibrium state with respect to the surface.

In this environment each radioactive atom has some freedom of movement and each kind (element) will interact with the surface in its own characteristic manner. The major interaction with the surface in this case is adsorption of individual elements (especially the metallic elements). The alkali elements (like sodium or cesium) do not adsorb on surfaces very strongly, the alkaline earth elements adsorb in larger extent, and the rare earth elements to a greater extent than the alkaline earths. The degree of adsorption is in order of the charge on the ions from +1, +2, to +3. The equilibrium amount of each adsorbed depends on the amount of each present initially in the drop. The amount directly adsorbed by the surface cannot be removed without either removing some of the surface, or without imparting a great deal of energy to the surface layer either by physical or chemical means. Water washing, for example, simply washes away the equilibrium amount left in the salt layers above the surface.

The Freundlich adsorption isotherm can be adapted to describe the adsorption process and subsequent washing of the surface. For a given element, it is—

$$F_j=R_j/I=a_jI^{n_j-1} \quad (1)$$

in which I is the initial level (later defined in total r/hr of which element j contributes a stated fraction at the time, t, after detonation; R_j is the amount left after washing (i. e., the amount adsorbed); and a_j and n_j are the impirical adsorption constants. The fraction remaining is—

$$R_j=a_jI^{n_j} \quad (2)$$

equations (1) and (2) apply either to a single drop or to the whole surface if at least a single layer of drops has been deposited. The intermediate situation is for rather low contamination levels and requires rather complicated equations; therefore, the following treatment will assume a serious contamination of the surface as the lower initial level of interest. For chemisorption which obeys equation 2, n_i is less than 1 so that the fraction remaining decreases with decreasing initial level.

In this type of fallout, another interaction can take place within the water drop either during its fall to earth or after it lands. Likely bomb and target structural materials will include fairly large amounts of iron, aluminum, etc. These materials will be oxidized and will form hydrous precipitates in the water drops. Many of the radioactive atoms will adsorb or mix with these precipitates. When these are present, a three-way interaction occurs on the surface rather than just the one previously described. Simple washing methods will dissolve only a small amount of the precipitates once they are dried on the surface, and during the process an equivalent amount of the radioactive elements will be released.

A rigorous mathematical solution of all the physical chemistry equations and material balance equation for the three-way process cannot be made; however, suitable approximations can be made for simple water washing of the surface. The fraction remaining for this case is—

$$F_i = a_i I^r j + \frac{I}{k_i + I} \qquad (3)$$

in which, for a given element,

$$K_i = dK_c V / q_r(t) \qquad (4)$$

in which (1) d is the density of the hydrous oxides.
(2) V is the equivalent initial volume of the fallout (before evaporation begins), deposited per unit area of surface.
(3) K_c is the equilibrium constant for the distribution of the element between the liquid and solid phase,
and (4) $q_r(t)$ is the ratio of the weight of the bomb (and target, as Al, Fe, etc.) per unit area to the amount of radioactive elements present; $q_r(t)$ therefore depends on the yield and is given by

$$q_r(t) = \frac{kM_B Y(t)}{bW[A_{FP}(t) + a_I(t)]} \qquad (5)$$

in which (1) M_B is the total mass of bomb (and target material thrown up),
(2) $Y(t)$ is the ratio of r/hr to d/m per unit area at time, t, after detonation and depends on the photon energy spectrum,
(3) W is the total yield of the weapon,
(4) b is the ratio of fission to total yield,
(5) $a_{FP}(t)$ is the activity of the FP from 10^6 fissions in d/m at time, t.
(6) $A_I(t)$ is the sum of the induced activities for 10^6 fisisons in d/m at time t.
and (7) K is a constant relating the fission yield and the number of fissions in appropriate units.

The various quantities illustrate the kind of weapon or detonation parameters which are related to the chemical interaction at a surface many miles away from the attack as well as the information required to properly interpret decontamination test experimental results.

LAND FALLOUT

Land fallout will consist of soil material, bomb structural and target materials, and radioactive products. The bulk of the fallout material from a surface detonation will be soil particles in which the radioactive elements are fixed. Therefore a decontamination procedure which moves the particles from a surface also moves the radioactive material.

In this case, the fallout particles maintain their size all through the process and since their density is high, the majority fall more vertically than the seawater fallout (in same wind speed), and, where the initial deposits are high enough to be of concern the horizontal surfaces will be more highly contaminated than vertical ones.

For surfaces which are contaminated with more than a single layer of particles, only the bottom layer actually "contaminates" the surface: Most decontamination methods are capable of removing all the superficial layers of particles. If a method removes all but the surface layer (or, all layers and all particles greater than a given size in contact with the surface), then the amount left after decontamination is a constant, independent of initial deposit. For this process, the fraction of the mass of fallout remaining is

$$F_m = \frac{R_M}{y} \tag{6}$$

in which R_M is a constant dependent on the particle size and method of decontamination and y is the initial deposit in mass of (solid) fallout per unit area. The mass representation is used here to emphasize the fact the soil particles and not radioactive atoms are being acted upon during the contamination and decontamination process.

For surfaces which are contaminated with less than a single layer of particle, the above mechanism of removal is postulated for the fraction of the area which is covered with particles. Since the landing of a given particle on a given spot on a surface is a statistical process with the probability of the next particle landing on a "clean" spot being proportional to the clean area, the fraction of area covered at any time (say, at the end of fallout) will be

$$f = l - e^{-\alpha y} \tag{7}$$

in which α is a constant called the spreading coefficient; its value depends on the average particle size and the roughness of the surface. Thus the general equation for levels of initial deposit is

$$F_m = \frac{R_M(1-e^{-\alpha y})}{y} \tag{8}$$

The fraction, f or $(i - e\lambda^{y})$, becomes one for a single layer of particles at which level equation 8 reduces to equation 6.

Equation 8 is converted to radiation intensities by means of a quantity called the mass contour ratio $M\lambda rt)$, in units of the ratio mass of fallout per unit area to r/hr. Briefly, the mass contour ratio is given by

$$M_r{}^{\lambda}t) = \frac{f'k'A\lambda W^{(n-1)}}{bY(t)[a_{FP}(t) + a_I t]} \tag{9}$$

in which (see equation 5)

(1) $A\lambda W^n$ is the scaling relation for the mass of material thrown out of the crater,

(2) n is an empirical constant,

(3) $A\lambda$ is an empirical parameter depending on the scaled height or depth of burst, λ

(4) λ is defined as the height or depth of burst in feet divided by the cube root of the yield in pounds of TNT,

(5) k' is a converting yield to fissions and other units, and

(6) f' is the fraction of the crater mass which mixes with the radioactive elements.

In radiation intensities, equation 8 is

$$F_r = \frac{R_M(1-e^{-\alpha M_r(t)I_r})}{M_r(t)I_r} \tag{10}$$

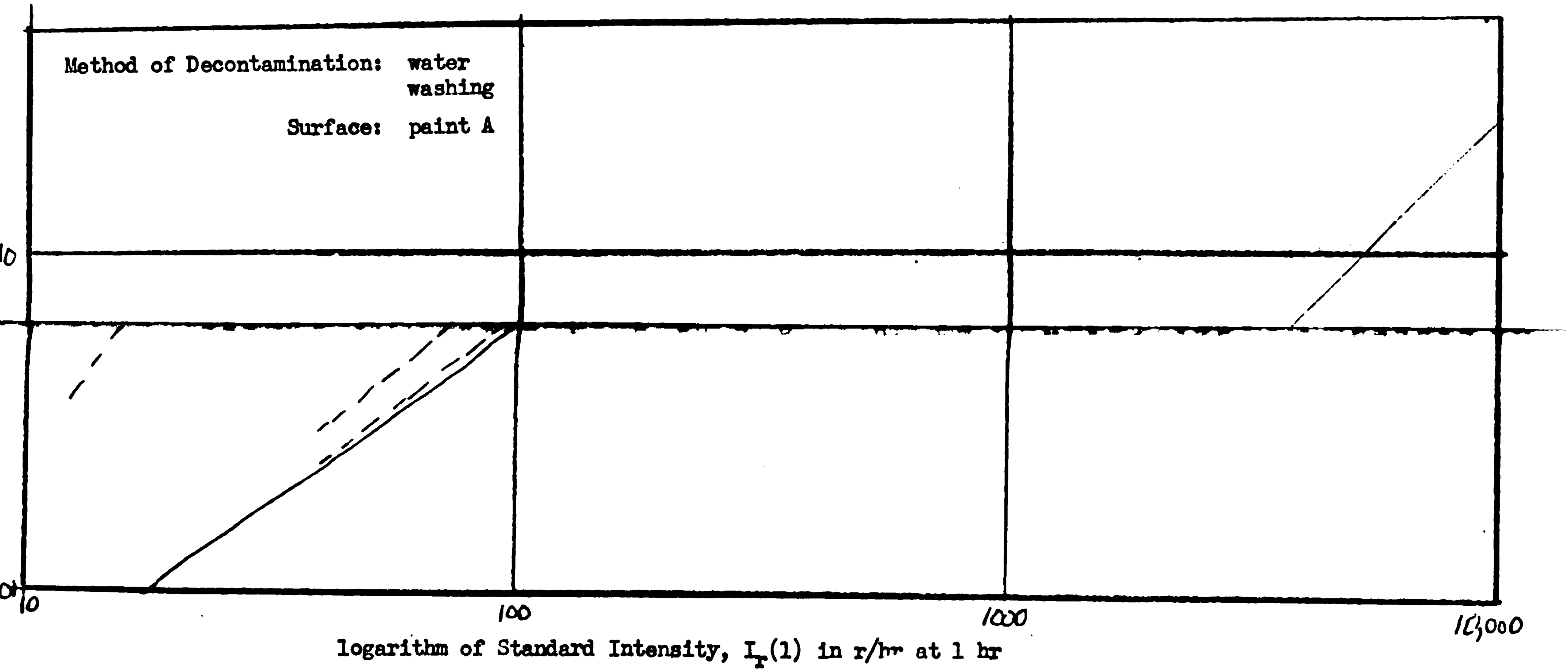
Harbor fallout

Harbor fallout can be either like sea-water fallout or like land fallout or a mixture of any combination of the two. A low yield burst on the surface of a deep harbor would give a sea-water fallout; a high yield detonation on the surface of a shallow harbor will produce a land fallout.

For the intermediate cases, the fallout will consist of sea water, harbor bottom (soil), bomb structural and target materials, and radioactive elements. The composition of fallout from harbor detonations can be described by their solid to liquid ratio, β.

Experimental data indicate that the additional phase (soil) to the seawater fallout induces only a negligible added interaction for most radionuclides and thus the total effect can be treated as a simple mixture of sea-water and land fallout. Where this is so a single representation can be made for all possible

Fig. 1 Predicted Radiation Levels after Decontamination at D + 7d as a Function of Standard Intensity in R/hr at 1 hr



types of fallout. The general equation, in terms of the ratiation intensity at H+1 hr, is

$$F_r(f) = \left[\exp - \frac{\lambda\beta}{1+\beta} M_r(1) I_r(1)\right] \sum_{j=1}^{j=n} P_i(t) F_i(t) + \frac{R_M}{M_r(1)_r I(1)} \left[1 - \exp - \frac{\lambda\beta}{1+\beta} M_r(1) I_r(1)\right] \quad (11)$$

$$F_i(t) = a_{jr}(t)[I_r(1)]^{n_i(t)-1} + \frac{I_r(1)}{K_{jr}(1,t) + I_r(1)} \quad (12)$$

in which $P_j(t)$ is the fraction of the radiation intensity contributed by the radionuclides of element j; the sub r indicates an evaluation in terms of r/hr, the (1) indicates an evaluation in terms of r/hr at 1 hr after burst, and (t) indicates the parameter depends upon the time the surface has been contaminated—i. e. requires evaluation for the time, t, after burst when the decontamination is carried out.

The results of some laboratory scale data from synthetic fallout together with constants for a hypothetical nuclear bomb were used to evaluate other empirical constants. These were used to compute the final levels for a decontamination at 7 days after burst for initial levels ranging from 10 to 10,000 r/hr at 1 hr. The curves for a β of zero (sea-water fallout) to a $\beta \geqslant 1{,}000$ (land fallout) at selected intervals are plotted in figure 1.

At the present time, there is not enough data available to determine a similar three dimensional decontamination surface (or even a partial surface) for any available reclamation method-surface combination. Since large scale reclamations are expensive and difficult, the preferable experimental technique would be to investigate the nature of the decontamination surface for a series of method-surface combinations by use of small-scale experiments in the laboratory and to check these with a few carefully chosen large-scale experiments with sufficient correlation experiments to make proper adjustment of the equation parameters.

Contaminability of Targets

The vulnerability of targets to contamination by fallout must consider three parameters:

(*a*) Does the fallout contact the surface?
(*b*) Once in contact, does it remain on the surface?
(*c*) How tenaciously is it attached, i. e., how easy is it to remove?

Such information is important for:

(*a*) Predictions of the relative radiological hazard within the target complex so as to exploit this variability operationally.

(*b*) Predictions of the over-all vulnerability of structures that incorporate shielding.

(*c*) Design and planning criteria for recovery procedures.

(*d*) Design criteria to provide minimum vulnerability of targets.

Factors influencing the contaminability of targets are:

(*a*) Gross geometry and configuration which determine the airflow patterns around the target and/or influence the "drainage" of material from the target surfaces.

(*b*) Physical and chemical characteristics of surface materials, i. e., roughness, porosity, adsorbability, chemical reactivity, etc., which influence the "entrapment" of fallout and ease of loosening, removal, and transport of contaminant by decontamination processes and/or natural weathering.

(*c*) Meteorological conditions which determine the initial distribution of fallout, and its resuspension and/or redistribution.

(*d*) The physical and chemical characteristics of the fallout, i. e., type (deep water, harbor, or dry land), chemical state, particle size, density, etc., which influence the "flight" characteristics, the impact and retention characteristics and the tenacity with which it is held to the surface.

Various laboratory and field tests have been made of the contaminability of surface materials as related to fallout characteristics and angle of inclina-

tion.[1,2,3,4] The contaminability of targets as related to micrometeorology and geometry have not been studied directly, but some information has been derived from experiments with other objectives.[5] As an example, a ship was exposed to fallout from a deep-water detonation.[6,7] The fallout arrived in a 15- to 20-knot wind on the starboard beam.

The following results were obtained:

(*a*) The contamination level (240 readings) on horizontal surfaces varied from 16 percent to 400 percent of the average, i. e., the largest was 25 times higher than the lowest.

(*b*) The gamma radiation level at 3 feet above the deck varied by a factor of 10.

(*c*) The average contamination level for vertical surfaces varied from the average horizontal reading as follows:

1. Forward part of the ship: 40 percent of horizontal average.
2. Aft part of the ship: 20 percent of horizontal average.
3. Lee side: 10 percent of horizontal average.
4. Windward side: approximately equal to horizontal average.

(*d*) Test panels at the stern of the ship had an average contamination level on vertical surfaces three times higher than levels on horizontal surfaces.[8]

Such data cannot be extrapolated or used for predictions without a better understanding of all of the factors involved.

In another example, small buildings and panels of typical building materials were exposed to fallout from land detonations.[4] The contamination levels on typical roofing materials was as much as 300 times higher than that on typical wall panels; or a vertical to horizontal relationship of about 0.3 percent. For panels of the same material, vertical readings were about 10 percent of the horizontal.

The two examples indicate considerable difference in the vertical to horizontal relationships. The characteristics of the fallout appear to have had a considerable influence on this distribution. For instance, the land detonation normally produces a "dry" fallout composed primarily of material from the crater. One can expect masses of 3 to 300 grams of material per square foot to be associated with significant radiation levels at early times. The fallout being a dry powder has little tendency to stick on vertical surfaces.

The fallout from deep-water detonations is largely composed of sea water salts. However, much of the water may evaporate, leaving particles that are damp, semicrystalline masses of a sticky nature. They are capable of sticking to vertical surfaces.

As indicated very little is known of the overall problem of contaminability. It is obvious, however, that two assumptions often made, i. e., ((1) that the fallout is distributed homogeneously on a uniform infinite plane, and (2) that vertical surfaces are not appreciably contaminated) are subject to serious limitations. The ability of a tactical force and/or a civilian population to exploit the variability of the fallout pattern depends upon knowledge we do not have on contaminability.

The contaminability of personnel exposed to the fallout event or working and living in contaminated environments is largely unknown. A study[9] indicating the significance of beta contact hazard to personnel and a requirement for the mass decontamination of personnel, emphasizes the need for additional contaminability information.

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Cost of Reclamation

Considerable data has been collected regarding the effectiveness of reclamation of targets contaminated by local fallout. The feasibility of applying these methods depends upon the following parameters:

(a) The time required to perform the reclamation must be short enough to make an appreciable saving in radiological exposure to mission personnel,

(b) The radiation exposure to reclamation personnel must be justified by the saving in exposure of mission personnel,

(c) The effort (manpower) and logistics required to reclaim the target must be compatible with the total effort available.

Thus, the cost of reclamation as measured in operating time, effort, radiation exposure, equipment, and supplies is an important determination.

It is impossible to generalize on these quantities for they are influenced by many factors.

The type of fallout, whether it be from a deep water, harbor or land detonation, influences the rate and/or method of decontamination. A deepwater-type fallout can be removed only to an extent of about 60 percent for a firehosing, scrubbing operation on ships,[1] the rate being about 40 square feet per minute. The same decontamination procedure at 6 times the rate of operation on a paved area contaminated by dry-land-type fallout will yield a removal of about 98 percent.[2] To achieve an equivalent removal on the ship, a surface removal technique would be required. Typical rates of operation are about 20 feet per minute for paint stripping[3] and about 7 feet per minute for removing a ⅛-inch thick layer of wood from the flight deck.[4]

The amount (or mass) of fallout on a surface influences the rate, particularly for harbor and dry-type fallout that must be transported over horizontal surfoes for considerable distances. The following table shows an example of how the rate decreases with increasing masses of dry fallout for motorized flushing.[2]

Dry fallout gm/ft:[2]	*Motorized flushing rate, ft.²/min.*
10	670
33	650
100	580
330	300

The mass of fallout has no effect on the rate of operation for surface removal or earth moving techniques.

The rate of operation is influence by the surface characteristics of the target, rough surfaces, e. g., wood shingles, requiring longer time than smooth, e. g., metal surfaces. The following table is an example of the influence of surface roughness on rate of operation:[2]

Firehosing of dry contaminant

Material	Effectiveness (percent removed)	Rate (ft²/min/hose)
Corrugated metal	97	65
Composition shingles	95	50
Wood shingles	89	35

The rate of reclamation by earth moving is influenced by soil characteristics. Standard earth moving practice has developed considerable information on this subject.

[1] AFSWP, ITR 1323, preliminary report, Operation Redwing, project 2.9, Standard Recovery Procedure for Tactical Decontamination of Ships. Confidential.

[2] Field Evaluation of Cost and Effectiveness of Basic Decontamination Procedures for Land Target Components, Sartor, J. D., Curtis, H. B., etc., USNRDL–TR in preparation. Unclassified.

[3] Rates approaching 50 square feet per minute are possible if removal of only the surface layer of paint gives the required reduction in radiation intensity.

[4] Proof Testing of AW Ship Countermeasures, Operation Castle, project 6.4 WT-927, Molumphy, Bigger. Confidential.

The degree of mechanization obviously influences rate of operation. The following example compares firehosing rate with that of motor flushing for harbor-type fallout. Also shown are the influence of mechanization on effort and radiation exposure.[3, 4]

Criteria for comparison	Actual performance or cost		
	Firehosing	Motorized flushing	Relative cost FH/MF
1. Operating rate per unit, hr/10[6] ft[2]	222	30	7.4
2. Personnel required per unit	5½	2	2.75
3. Effort (direct labor), man-hr/10[6] ft[2]	1,210	60	20.0
4. Radiation shielding factor	1.0	0.5	2.0
5. Relative cost in radiation dose	1,210	30	40.0

Target complexity obviously influences rate of operation. For optimum performance, spacings between target components must be large enough to permit mechanized equipment to be used.

A simplified example will help indicate the time, manpower, and basic supplies required for recovery of a target complex. The following criteria are assumed:

(*a*) Target: City of San Francisco.
(*b*) Fallout: Harbor-type at 33 gms/ft[2].
(*c*) Area to be recovered: About 25 square miles consisting of—
1. All paved areas.
2. All industrial and commercial areas and buildings.
3. 50 percent of the park areas.
4. 10 percent of the residential areas and buildings.

(*d*) Methods: Firehosing and earth moving.

The following table indicates an estimate[5] of the cost of reclaiming these critical areas:

Cost of decontaminating critical areas of San Francisco through use of available firefighting and earth moving equipment for removing slurry contaminant

	Firehosing			Earth moving, land areas	Grand total
	Roofs	Paved surfaces	Subtotal		
1. Time to complete decontamination (24-hour days)	16.8	11.7	28.5	13	
2. Direct labor (number of men)			4,000	2,800	6,800
3. Total labor, direct and support (number of men)			6,000	4,900	10,900
4. Total effort (8-hour man-days)	101×10^3	70×10^3	171×10^3	64×10^3	235×10^3
5. Labor cost at $10 per man-day			$\$1.71\times10^6$	$\$0.64\times10^6$	$\$2.35\times10^6$
6. Water required for decontamination (gallons)	362×10^6	314×10^6	676×10^6		
7. Fuel required (gallons):					
(*a*) Gasoline	145,000	101,000	246,000	95,000	341,000
(*b*) Diesel fuel				195,000	195,000

As can be seen, the reclamation is feasible in what appears to be a reasonable time. The amount of equipment required is within the capability of existing sources in San Francisco. The manpower is not too excessive considering the numbers of people available. The water requirements are within the capability of the normal supply. Fuel consumption is less than normal daily requirements. The greatest problem would undoubtedly be that of organizing, training, supervising, and controlling 11,000 men.

Automatic decontamination devices such as the washdown system have, as an important advantage, the capability of reclamation at very early times with no expenditure of manpower or radiation exposure. They can be extremely effective (i. e., removal of 90–95 percent) even on sea-water-fallout.[4] However, they do require expenditure of funds before the war begins.

[5] Engineering Approach to Radiological Decontamination. Hawkins, M. B. (Paper to be given ASME semiannual meeting, San Francisco, June 1957.) Unclassified.

THE NEED FOR A NATIONAL PROGRAM IN NUCLEAR COUNTERMEASURES

The full exploitation of nuclear weapons and nuclear power requires that full preventive measures be employed at all times to keep potential exposure below hazardous levels, *and* that the capability of reclamation after any nuclear mishap be high.

The current policies of the AEC and DOD, backed by the very competent Health and Safety Division in the AEC installations, have provided a generally satisfactory national program based on *preventive* and control measures. No similar program exists to fulfill the reclamation requirement, or to prepare the way for successfully coping with a general increase of radioactive background above that imposed from natural sources. Such an increase is inevitable—both on a general scale and on a more limited scale. The general buildup is predominantly related to weapon detonations. The more limited scale is confined to such areas as the exclusion zones of the Nevada test site, the Reactor Test Station, Arco, Idaho, etc. From the other extreme, there is an increasing demand to establish contamination specifications for the general release of previously contaminated equipment into the established industrial channels.

It is proposed that a positive national program of nuclear countermeasures development be undertaken to add preprotection and reclamation capability to the established preventive measures.

Four completely different types of end-use application are apparent:

(1) Increasing the nuclear resistance of military operating forces in the field.

(2) Continental defense of the United States in time of total nuclear war.

(3) Reclamation from a nuclear mishap in times of peace.

(4) Adaptation of the established economic system to absorb the applications of nuclear energy that are already developed, or under development.

The four applications are common in that one is faced with the impact of radiation and radioactivity on the civilian and/or noncombatant society. The control techniques used during the research, development, and production phases are no longer sufficient since these techniques rely solely on control and preventive measures.

The four applications differ in that the criteria relating the nuclear or radiological environment to the permissible dose or acceptable hazard are not completely common.

However, much of the research and development up to the point of final application is interchangeable. A unified research and development program should have a large payoff value on all four fronts. It also appears that the DOD, AEC, FCDA, and possibly the PHS all have a vital interest in such a unified program.

SUMMARY OF NUCLEAR WEAPON COUNTERMEASURE SYSTEM DEVELOPMENT PROGRAM PROPOSAL (SPECIAL TEST PROGRAM COMPONENT)

This memorandum summarizes the proposals advanced by the United States Naval Radiological Defense Laboratory as representing the fastest and most economical way of developing a national capability in nuclear weapon countermeasures. This proposal has formed the basis of discussions with Mr. R. L. Corsbie and Dr. A. W. Bellamy, representing the Atomic Energy Commission, concerning the manner in which nuclear weapon tests could be more profitably exploited. The same proposal has been discussed with the FCDA Planning Office, but has not been formally developed.

To insure the greatest level of national readiness in minimum time, the nuclear weapon countermeasure system must be developed with the same care that has gone into the development of the offensive weapon systems. It is proposed that a nuclear weapon countermeasure system development program be established, and that a *proof test* of the proposed system be made at a special test to be conducted in accordance with the attached schedule. This test will:

(1) Proof test proposed standard shelter designs.

(2) Proof test proposed rapid reclamation systems.

(3) Establish an experimental basis for determining criteria required to achieve final recovery.

Such a program cannot succeed if projects are submitted by invitation to all agencies that may have an interest in the subject. The test projects must be carefully planned to proof test an integrated system and must carry through all three time phases: emergency, operational recovery, and final recovery. The United States Naval Radiological Defense Laboratory believes it has the competence to develop such an integrated system. Adequate criteria exist to justify an operational development program of both emergency and operational recovery phases. Adequate criteria do *not* exist to establish feasible systems for the final recovery phase. Therefore, this test must be used to aid in the experimental determination of such criteria including food management and agricultural reclamation. The capability of existing instrumentation and doctrine to provide the required radiation and operational control data will be able to be determined realistically.

This program is only one part of the required national weapon countermeasure program. However, it provides the essential base against which real progress can be evaluated.

The proposals submitted to Mr. Corsbie for Operation Plumbbob are developmental projects covering some aspects of the emergency and operational recovery plans.

Outline of Essential Timetable

R&D program leading to selection of system components and establishment of necessary projects	Test date minus 3 years	
	Test date minus 2 years	Site selection and program scope completed
	Test date minus 1 year	Submission of complete test program plan
Construction, equipment procurement, training		
	TEST DATE	
Operational recovery begins		Emergency phase complete
Shelters, situation appraisal, etc.		
Transition to final recovery begins	Test date plus 6 months	Final report on emergency phase program
	Test date plus 9 months	Operational recovery complete
	Test date plus 18 months	Final report on operational recovery phase program
Experimental program to measure incorporation of critical elements into the environment and their uptake into animals. Agricultural reclamation experiments.	Test date plus 3 to 5 years	

Evaluation of the state of knowledge relating to radiological countermeasures development[1]

	Continental defense	Peacetime application
Transport mechanism	A	C
Nuclear and chemical properties	A	B
Contamination-decontamination phenomena	C	C
Reclamation methods	B	C
Component development	C	C
Shielding and terrain effects	B	B
Shelter development	B+	(2)
Final recovery	C	C
Systems development and analysis	B	B

[1] This table was developed by Dr. Paul C. Tompkins, USNRDL, Mr. R. Corsbie, and Mr. J. Deal, DBM of the AEC, to guide the development of projects to improve the nuclear weapons defense capability of the Atomic Energy Commission. It has been examined by the technical staff of the USNRDL and is considered to be a fair evaluation of the current state of real knowledge.
[2] Not applicable.

NOTE.—State of knowledge and effectiveness of application based on the ability to apply determinable numbers in a wide range of actual cases:
A—Adequate for practical applications
B—Inadequate for practical applications
C—Little known

(Submitted by Department of Defense)

U. S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

SAN FRANCISCO, CALIF

From: Commanding officer and director.
To: Chief, Bureau of Ships (code 110).
Subject: Congressional hearings before the Joint Committee on Atomic Energy concerning the nature of radioactive fallout and its effects on man, scheduled for May 27 through June 7, 1957.
Reference:
(*a*) Ch, BuShips ltr A18 (110) Ser 110–1447 of June 6, 1957.
(*b*) CO and Dir, USNRDL Conf ltr 900–0801 PCT: lcm of May 16, 1957.
(*c*) CO and Dir, USNRDL ltr 900–803 RCL: rts of May 23, 1957.
Enclosure: (1) Biographies of contributors to written statements submitted for subject hearings.

1. As requested by reference (*a*), enclosure (1) forwards biographies of contributors to the written statements submitted for the subject hearings, arranged in an alphabetical listing. The authors and identifying titles of the USNRDL survey of various aspects of radiological fallout from nuclear weapons are given below in the order submitted.

(*a*) Reference (*b*):

I.	Prediction of Fallout	E. A. Schuert C. F. Ksanda
II.	Measurement of Fallout	T. T. Triffet
III.	Physical and Radiochemical Properties of Fallout	N. E. Ballou C. W. Adams
IV.	Environmental Aerosol Analysis	A. L. Baietti
V.	Radiological Countermeasures	C. F. Miller

(*b*) Reference (*c*):

I.	Mass-Activity Relationships Derived from Fallout Measurements.	C. F. Miller
II.	Relation of Radioactive Decay to Countermeasures.	C. F. Miller
III.	Physical Chemistry of Fallout as It Relates to Decontamination Countermeasures.	C. F. Miller
IV.	Contaminability of Targets	M. B. Hawkins
V.	Cost of Reclamation	M. B. Hawkins

VI. General information on a nuclear countermeasures program: } P. C. Tompkins

A. The Need for a National Program in Nuclear Countermeasures.

B. Summary of Nuclear Weapon Countermeasure System Development Program Proposal.

C. Evaluation of the State of Knowledge Relating to Radiological Countermeasures Development.

2. The material submitted by the USNRDL was reviewed and edited by Drs. E. P. Cooper and E. R. Tompkins. Because of their valuable contributions, their biographies are included in enclosure (1).

By direction:

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Mech. Engr., Isotopes Div., Atomic Energy Cmn. 1948; Treas, and Ch. Engr. Scientific Service Inc., 1948–50; Naval Radiological Defense Lab., San Francisco 24, Calif., 1950–51; Hd Tech. Dev. Br. 1951– .

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24 Roosevelt Circle, Palo Alto, Calif. Home phone: None. Office phone: MIssion 8–6900, ext. 423. Date and place of birth: 1918, Osceola, Wisconsin. Education: B. S., Math., State Teachers College, River Falls, Wisc. 1940; M. S., Chemistry, Univ. of Calif. 1948; Ph. D., Chemistry, Iowa State College, Ames, Iowa, 1951. Work History: Jr. Chemist, Iowa State Col., 1948–51; Naval Radiological Defense Laboratory, San Francisco 24, Calif., 1952; Hd, Countermeasures Evaluation Br., 1956– .

Schuert, Edward A.

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Tompkins, Paul C.

2765 Summit Drive, Hillsborough, Calif. Home phone: DIamond 4–4774; office phone, MIssion 8–6900, ext. 400. Date and place of birth: 1914, Walla Walla, Wash. Education: A. B., Whitman College, 1935; Chicago, 1936–37; Ph. D., biochemistry, California, 1941. Work History: Asst. biochem., Calif., 1940–41; chem., Stanford, 1941–42; Research Assoc., 1942–43; Metallurgical Lab., Chicago, 1943–45; Sr. Chemist, Clinton Lab., 1945–47; Prin. Biochemist, Oak Ridge Nat. Lab., 1948–49; Staff Advisor to Sci. Director, Naval Radiological Defense Laboratory, San Francisco 24, Calif., 1949–50; Assoc. Sci. Dir., 1950–51; Sci. Dir., 1952– .

DEPARTMENT OF THE NAVY

OFFICE OF NAVAL RESEARCH

Washington, D. C.

From: Chief of Naval Research.
To: Chief of Legislative Liaison.
Subject: Congressional hearings before the Joint Committee on Atomic Energy concerning The Nature of Radioactive Fallout and its Effects on Man, scheduled for May 27 through June 7, 1957.
Reference: (a) OLL: INV: ACJ: gms memo 6-1182 of June 3, 1957.

1. In accordance with reference (a), the following biography is submitted:

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A. B. METSGER,
Deputy and Assistant Chief of Naval Research.

HEADQUARTERS, AIR WEATHER SERVICE,
MILITARY AIR TRANSPORT SERVICE,
UNITED STATES AIR FORCE,
Washington, D. C., May 17, 1957.

STATEMENT BY LEROY H. CLEM [1] OF THE AIR WEATHER SERVICE ON FALLOUT PREDICTION

The prediction of radioactive fallout is a combined meteorological and radiochemical problem. The mission of the Air Weather Service does not include any treatment of the radiochemical portion of the problem but is confined to the indication under emergency wartime conditions of the effect of only the meteorological variables on the transport of radioactive debris during its fall back to earth within a few hundred miles of the site of a nuclear detonation. To accomplish this mission requires accepting certain rather gross assumptions about such nonmeteorological variables as the initial distribution of contaminated particles in the stabilized cloud and the particle fall rates. Thus, given these gross assumptions, the only additional factors with which the Air Weather Service forecasters are concerned are the time and location of the occurrence of a nuclear detonation and the best estimate of the wind field through which the radioactive debris will fall.

The idealized meterological solution to this problem involves the computation of a whole family of three-dimensional trajectories starting from various levels of the atomic cloud. By considering changing wind conditions, these trajectories represent the fall paths of a variety of particles (of differing size and shape) which were present at the various levels in the cloud when it stopped rising. Such a solution is beyond the present state of the science of meterology. Therefore, the Air Weather Service, as well as other agencies, had to make certain simplifying meterological assumptions in order to be able to handle the forecast problem.

The generally accepted method is based on the following main assumptions:

(a) The winds at selected levels in the middle of layers (e. g., 10,000 feet thick) are representative of the windflow that would effect the drift of the particles while they are falling through that layer.

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[1] Bachelor of science degree, Brown University; certificate for graduate meteorological engineering, New York University; master of science degree in meteorology, Massachusetts Institute of Technology; 13 years of professional experience in meteorology; during World War II served as an aerological officer in the Navy; several years experience with the U. S. Weather Bureau; serves as the expert on fallout-prediction problems, high level wind problems and forecast capabilities. Assigned to the Technical Service Branch, Technical Requirements and Services Division of Scientific Services of Headquarters, Air Weather Service. (Submitted by Department of Defense.)

(*b*) The wind sounding (observed or forecast) for the upper-level winds applicable at the point of detonation is representative of the windflow throughout the course of the ensuing fallout.

It is believed that assumption (*a*) does not introduce much error; however, assumption (*b*) is both the heart of the technique and the most questionable of these two assumptions. Although experience has shown that persistence forecasts (implied in (*b*)) of upper-level winds are equal to or better than other available forecast methods for the first few hours, variability of the wind, when coupled with the inaccuracies of wind observations and forecasts, introduce sizable errors in the method. The average error in the resultant 6-hour forecast fallout plot derived from this method is of the order of ±10 to ±30 degrees in direction and 30 to 40 percent in distance. The forecast errors involving fallout coming from the higher levels of radioactive clouds formed by large weapons are relatively smaller than those for fallout from the lower levels of the clouds.

However (even in view of these inaccuracies), by using the stated meteorological assumptions, it is possible to compute the most probable geographical area that may be contaminated by radioactive fallout following a surface or near-surface burst of a nuclear weapon. There are more sophisticated and time-consuming computational techniques available, involving more complex assumptions than (*b*) which are supposed to take care of some of the variability of the wind. However, evaluation tests have indicated that the slight decrease in the resultant errors from using these more complex methods does not justify the extra computational time and effort involved. The Air Weather Service method, based on a very simple and versatile 6-hour wind-vector technique, is equally useful in this country as well as overseas and can be evaluated for any desired area on the earth's surface or at altitudes normally used by aircraft. This method consists of adding the wind vectors from the layers through which the particle will fall and then (with an assumed fall-rate) a fallout plot is developed from this. This results in a time-space plot which delineates the areas which may receive fallout and the expected time of occurence. It should be noted that no attempt is made in this method to forecast levels of radiation intensities, relative or absolute.

Although this method for forecasting the close-in areas which are expected to be contaminated by falling radioactive debris does not achieve the accuracy and precision ideally desired (because of many unresolved factors, some of which are nonmeteorological), its accuracy (±10 to ±30 degrees in direction and 30 to 40 percent in distance from ground zero) is in line with the current state of the science. There are no techniques available today which can provide more than very generalized answers in a forecast situation involving large weapons.

STATEMENT BY COL. B. G. HOLZMAN[1] AND COL. NORAIR M. LULEJIAN,[2] AIR FORCE RESEARCH AND DEVELOPMENT COMMAND

Question. How does your organization predict fallout, given weapon yield, height of burst, type of terrain, and meteorological conditions? How reliable do you feel these forecasts are?

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[1] Born: Los Angeles, Calif., January 25, 1910. 1931: B. S., California Institute of Technology. 1933–34: Ph. D., candidate graduate study, California Institute of Technology. June 1945 to July 1945: Alamagordo, N. Mex.: meteorological adviser on first atomic test. August 1945 to January 1946: Asheville, N. C.: Chief, Research and Evaluation Division, Weather Service. February 1946 to August 1946: Washington, D. C., and Bikini, Marshall Islands: Atomic bomb tests, staff weather officer, Joint Task Force 1. September 1946 to August 1947: Washington, D. C.: Headquarters, air staff, research and development officer for atmospheric sciences. September 1947 to June 1948: Washington, D. C., Eniwetok, Marshall Islands: Atomic bomb tests, staff, weather officer, Joint Task Force 7; executive officer, long-range detection (AFOAT–1). July 1948 to June 1950: Washington, D. C.: Chief, Geophysical Sciences Branch, research and development, Headquarters, USAF. June 12, 1950, to August 23, 1951: Washington, D. C.: Chief, Research Division, assistant for atomic energy, headquarters, USAF. January, February, 1951: Nevada: Operations consultant to AEC, Nevada ranger, atomic tests. August 23, 1951, to June 17, 1952: Washington, D. C.: National War College. June 17, 1952, to September 1, 1952: Baltimore, Md.: Headquarters, Air Research and Development Command. September 1, 1952, to May 30, 1955: Albuquerque, N. Mex.: Deputy for Research and Development, and Chief of Staff, Special Weapons Center, Kirtland Air Force Base. May 30, 1955, to present: Baltimore, Md.: Director, Air Weapons, Headquarters, Air Research and Development Command. (Submitted by Department of Defense.)

[2] Native of Hawthorne, N. J., is a graduate of Columbia University (B. S. in 1939); worked as a research chemist for Ortho Products, Inc., in Elizabeth, N. J., for a period of

Footnote continued on following page.

Answer. The Air Force Research and Development Command has developed a simple method to predict the general area within which fallout may occur. An attempt was made for several years to develop a more rigorous treatment of the fallout problem; however, this approach was abandoned because of the inherent time and space variability of the atmospheric winds which introduces large errors in all fallout predictions. It is the opinion of Air Force Research and Development Command that in view of the large errors introduced by the variability of the winds, it is pointless to attempt a precise model of the radioactive distribution in the atomic cloud. The fallout pattern influenced by different types of terrain are completely masked by the very large errors introduced because of variability of the winds. Experience during past atomic-test operations has verified the fact that even when zero-hour-measured winds were used, thus eliminating all wind-forecast errors, the actual fallout never occurred in the exact region indicated by the observed winds. There was always a displacement varying up to 45° of the actual fallout from its calculated position. The reason for this is simple. The observed winds are valid over the target area for a relatively short time. Fallout may reach a distance of 150–250 miles downwind and it may take 6–18 hours for the local fallout to be completely deposited on the ground. During this 6–18 hours the winds change both in direction and in speed. There is not only this time variation, but also the space variation. In other words, the winds aloft over ground zero are not necessarily the same as winds 150 miles downwind. Furthermore, the method of measuring winds by the use of balloons introduces another serious error because of the inability to specify the true wind profile directly over ground zero.

It is questionable whether the time and space variability of the winds could be forecast with an accuracy exceeding ±15° in the direction of the winds. An error of 15° would spell the difference between an airbase or a city receiving either no radiation at all or possibly lethal concentrations of radiation from the local fallout of a single weapon.

We have considered fallout from the offensive and defensive points of view. For defensive purposes before we can make any reasonable estimates of the local fallout plot we need to know the total yield as well as the fission yield of the weapons, height of burst, and coordinates of ground zero. Even with all this information it will be impossible to delineate the fallout pattern with sufficient accuracy to predict whether a given military installation downwind of ground zero would receive no, little, or lethal concentrations of radiation. For offensive use a further complexity is introduced because most probably very little if any reliable meteorological information will be available over enemy territory. Therefore, in spite of our knowledge of the yield, height of burst, and ground zero on bombs, the fallout pattern over enemy territory would be equally if not more difficult to predict.

When many multimegaton weapons are exploded, the calculation of reasonably accurate fallout patterns becomes even more difficult. The validity of the requirement for ascertaining fallout patterns under these conditions becomes even more questionable because lethal contamination will occur over large overlapping areas regardless of the meteorology.

However, the above should not be construed to mean that we are unable to make generally correct predictions; for instance, as to what countries or large areas shall lie inside or outside the dangerous part of fallout patterns from distant bursts. A choice of burst height that prevents the fireball from touching the earth, essentially eliminates local fallout.

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2 years; entered military service in September 1942, and enrolled as an air cadet in meteorology in January 1943 at Grand Rapids, Mich.; received his commission as second lieutenant in September 1943; returned from overseas early in 1946 and served with Headquarters Air Weather Service until September 1946, after which time he was transferred to Headquarters, USAF, in the Pentagon. He left Headquarters, USAF, to enter a 3-year course in radiological engineering in September 1948; assigned to Headquarters, ARDC, in Baltimore since June of 1952. He is Chief of the Nuclear Applications Division of the Directorate of Air Weapons. (Submitted by Department of Defense.)

STATEMENT BY DR. DONALD M. SWINGLE[8] OF THE ARMY SIGNAL CORPS, EVANS, S. C., LABORATORY, FOR SUBMISSION TO THE JOINT COMMITTEE ON ATOMIC ENERGY

Question. How does your organization predict fallout, given the weapon yield, height of burst, type of terrain, and meteorological conditions? How reliable do you feel these forecasts are?

Answer. 1. The principles of fallout prediction used in the Signal Corps method are outlined below:

(*a*) The prediction procedure described assumes a surface burst of a nuclear weapon. Given the weapon yield, the dimensions of the cloud are estimated from a survey of previous test data. (See discussion below.)

(*b*) The cloud is split into layers, on the basis of available data on particle-size distribution, and the particle sizes in each layer are considered.

(*c*) Where each particle size in each part of the cloud will land is determined by trigonometry, considering rate of fall and the effect of wind. It is assumed that the latest available wind data is representative.

(*d*) Then the ground position of arriving fallout is plotted and overlapping contours are added together.

(*e*) A meteorological contour analysis of the resulting pattern is made and this is analyzed for dose-rate information.

(*f*) The time of arrival on the ground of each particle size for each original slice is calculated and analyzed for *time of arrival* and *time of ending*, if wanted, of fallout material.

(*g*) From consideration of the time of arrival and dose rate, the *total dose* for 48 hours is approximated.

In the above procedure, terrain has not been specifically considered.

2. The effective radiological activity predicted would be affected by the estimated height of the cloud. The ratio of fission to total yield of the burst will affect the estimated dose rates and the total dose.

3. If the height of the cloud is known, the height to which wind data is required is immediately known. Assuming the height of the cloud is not known, the height and diameter may be estimated from the meteorological conditions. The criterion for estimating the cloud height is the height of the tropopause. This is accomplished by adjusting the basic pattern design for location of burst and for the season.

4. The accuracy of fallout prediction is directly related to the accuracy of the basic information. The degree of reliability of the several factors and the variation of wind with time and space prohibit exacting prediction. The Signal Corps is studying the question of attainable accuracy. But data for vertification of pattern design is limited. Considering the factors outlined above and when the fission to total yield is known, it is hoped to attain fallout prediction within a factor of 2 for points within contour lines of 100 roentgens per hour or greater.

5. The details of a Signal Corps draft method of fallout prediction are being reviewed and the method is being modified. Consideration is being given to the effect of time and space variations of the wind. The present method utilizes an effective wind consideration at the point of burst to be applied throughout the pattern computation.

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[8] Physicist GS–14. Chief, Meteorological Techniques Secton, Meteorological Branch, Physical Sciences Division, Evans Signal Laboratory, U. S. Army Signal Engineering Laboratories, Fort Monmouth, N. J. Graduated Theodore Roosevelt High School, Washington High School, Washington, D. C., 1939; bachelor of science in math-science from Wilson Teachers College, 1943; master of science in meteorology from New York University, 1947; master of arts in engineering science and applied physics from Harvard University, 1948; doctor of philosophy in engineering science and applied physics from Harvard University, 1950. American Meteorological Society, World Meteorological Organization Working Groups, Institute of Radio Engineers, American Geophysical Union, American Association for the Advancement of Science, American Institute of Electrical Engineers, ad hoc groups under established coordinating agencies. Professional engineer in States of New York and New Jersey. During World War II participated in the first modification of existing radars for the specific purpose of weather observation. He has been intimately connected with later development of equipment and the development of radar techniques for observations of storms, precipitation areas, and other specialized parameters. Techniques concerned with local meteorology of particular importance to Army operations is another concern of his. Leading Army scientist concerned with methods of predicting fallout. His present efforts are directed toward a practical field method of prediction which will lead to information of sufficient detail for Army use. (Submitted by Department of Defense.)

MAY 24, 1957.

TECHNICAL PRESENTATION FOR THE JOINT COMMITTEE ON ATOMIC ENERGY HEARINGS ON THE SUBJECT, THE NATURE OF RADIOACTIVE FALLOUT AND ITS EFFECTS ON MAN, MAY 27–29 AND JUNE 3–7, 1957

Specifically on—

Topic VI. Atmospheric Transport, Storage, and Removal of Particulate Radioactivity
Topic VII. Local Fallout
Topic VIII. Delayed Fallout

Submitted by James G. Terrill, Jr.,[*] Chief, Radiological Health Program, Division of Sanitary Engineering Service, Public Health Service, United States Department of Health, Education, and Welfare

VI. ATMOSPHERIC TRANSPORT, STORAGE, AND REMOVAL OF PARTICULATE RADIOACTIVITY

Public Health Service fallout activities have emphasized the collection of data on the actual exposure of people which data can be used to modify operational procedures to reduce the exposures and to serve as a basis for studying possible chronic radiation effects.

B. Local fallout

Local fallout is initially of concern as an acute external gamma or beta irradiation hazard. For this reason our off-site radiological safety operations in Nevada and in the Pacific are based on external gamma readings obtained with portable survey instruments. This system of operation is based on the assumption that beta concentrations during this period are substantially in proportion to the gamma intensities. This assumption has been confirmed, in general, by results of beta measurements of air samples collected during the fallout periods in Nevada. Local fallout may, and has become of concern as an internal beta emitter after its decay to a level at which the gamma irradiation is no longer of concern from the standpoint of acute effects. Up to this time the Service has not attempted to measure alpha concentrations in local (or delayed) fallout although the amounts are presumed to be low.

A report of local fallout sufficiently detailed to be used for public health purposes is the Report of Off-Site Radiological Safety Activities from Operation Teapot conducted at the Nevada test site in the spring of 1955, prepared jointly by the Las Vegas Branch Office of the Atomic Energy Commission and the Public Health Service.[1] Comments concerning the predictability of local fallout and observed patterns of local fallout will be based on this report.

The Teapot report outlines Public Health Service responsibilities and the supporting services, including air support, provided by other agencies.

Data gathered during this operation make it possible to:

1. Compare predicted fallout with the fallout as it actually occurred;
2. Compare the radioactive cloud path with the deposition of activity on the ground; and
3. Report on observed patterns of local fallout in terms of external gamma radiation.

1. The predictability of local fallout.—Fourteen devices were detonated during Operation Teapot. In reviewing the data on predicted and measured fallout from these detonations, it was found that in 5 cases the prediction is in substantial agreement with measured fallout, while in 6 cases the actual deposition of fallout was significantly at variance with the prediction. Three devices were air detonated and no fallout prediction per se was used. Chart I illustrates a case where the fallout prediction compares favorably with the fallout which actually occurred. Chart II shows a typical deviation from the predicted fallout, while chart III shows a major deviation from the prediction.[1]

[*] Graduated from the University of Cincinnati in 1937 with a degree in civil engineering. Studied public health engineering at the Massachusetts Institute of Technology Graduate School from 1938–41. Since 1941 he has been active in the Public Health Service. Participated in the first Bikini tests. During the period 1948–51 he studied radiological defense under the sponsorship of the Armed Forces special weapons project at the U. S. Navy Postgraduate School and the University of California. He participated in and directed the Public Health Service activities related to the Nevada and Pacific test operations during 1953–57. Active in radiological committees of the American Society of Civil Engineers and the American Public Health Association. Member of the National Committee on Radiation Protection and the Nuclear Standards Board of the American Standards Association. Presently chief of the radiological health program, Division of Sanitary Engineering Services, Public Health Service. (Submitted by witness.)

[1] Report of Off-Site Radiological Safety Activities, Operation Teapot, Nevada test site, spring 1955.

It should be emphasized that these data are for gamma radiation only and represent only particulate material fallen from the cloud. They do not take into account isotopes, such as iodine, that may be in a gaseous form and may not follow the fallout pattern. We plan to study this as well as other problems related to fallout exposure during and following Operation Plumbbob as a part of our off-site operation carried out under agreement with Albuquerque Operations Office of AEC. This work also has the concurrence of the Division of Biology and Medicine of AEC.

CHART 1

FALLOUT PATTERNS

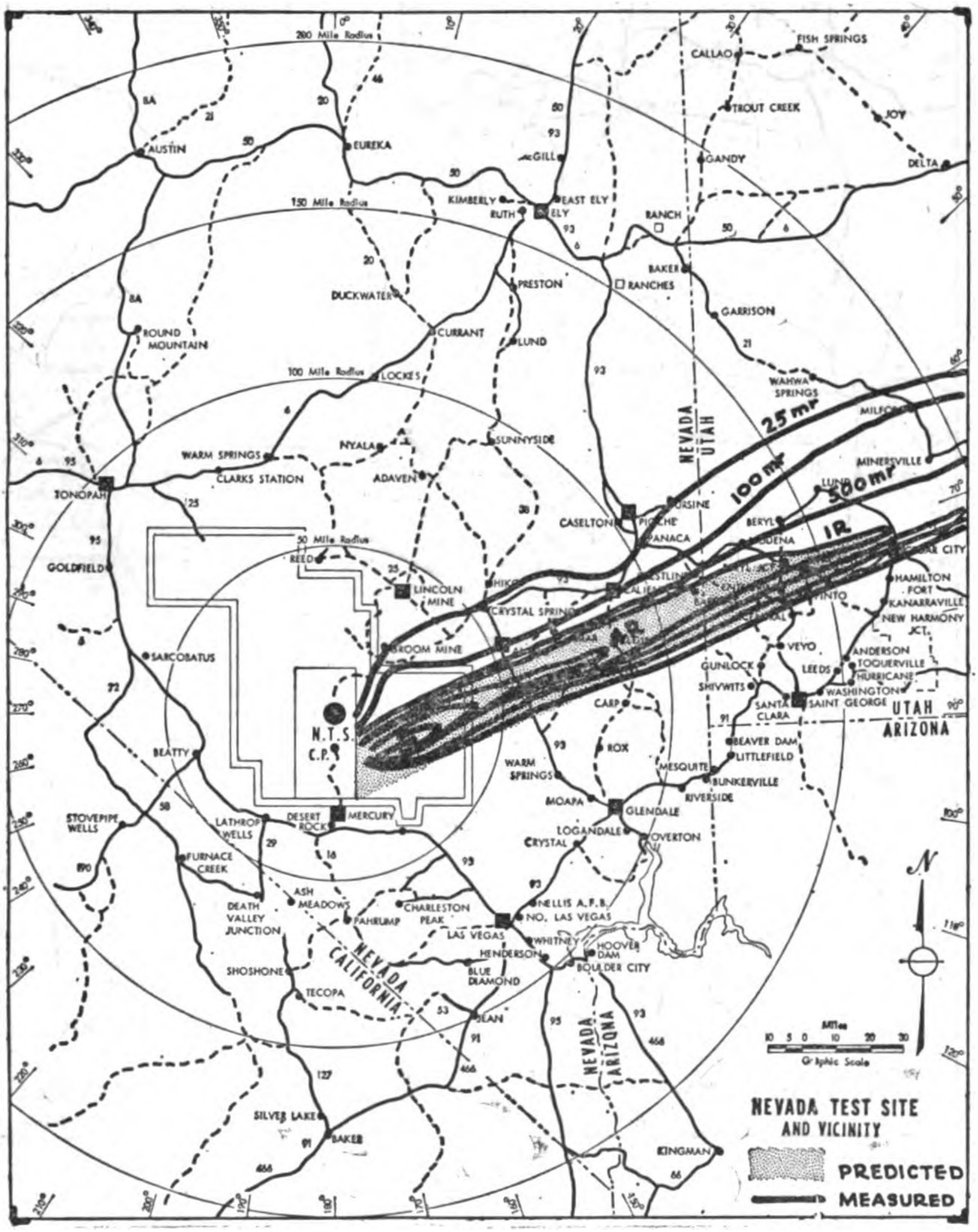


CHART 2

FALLOUT PATTERNS

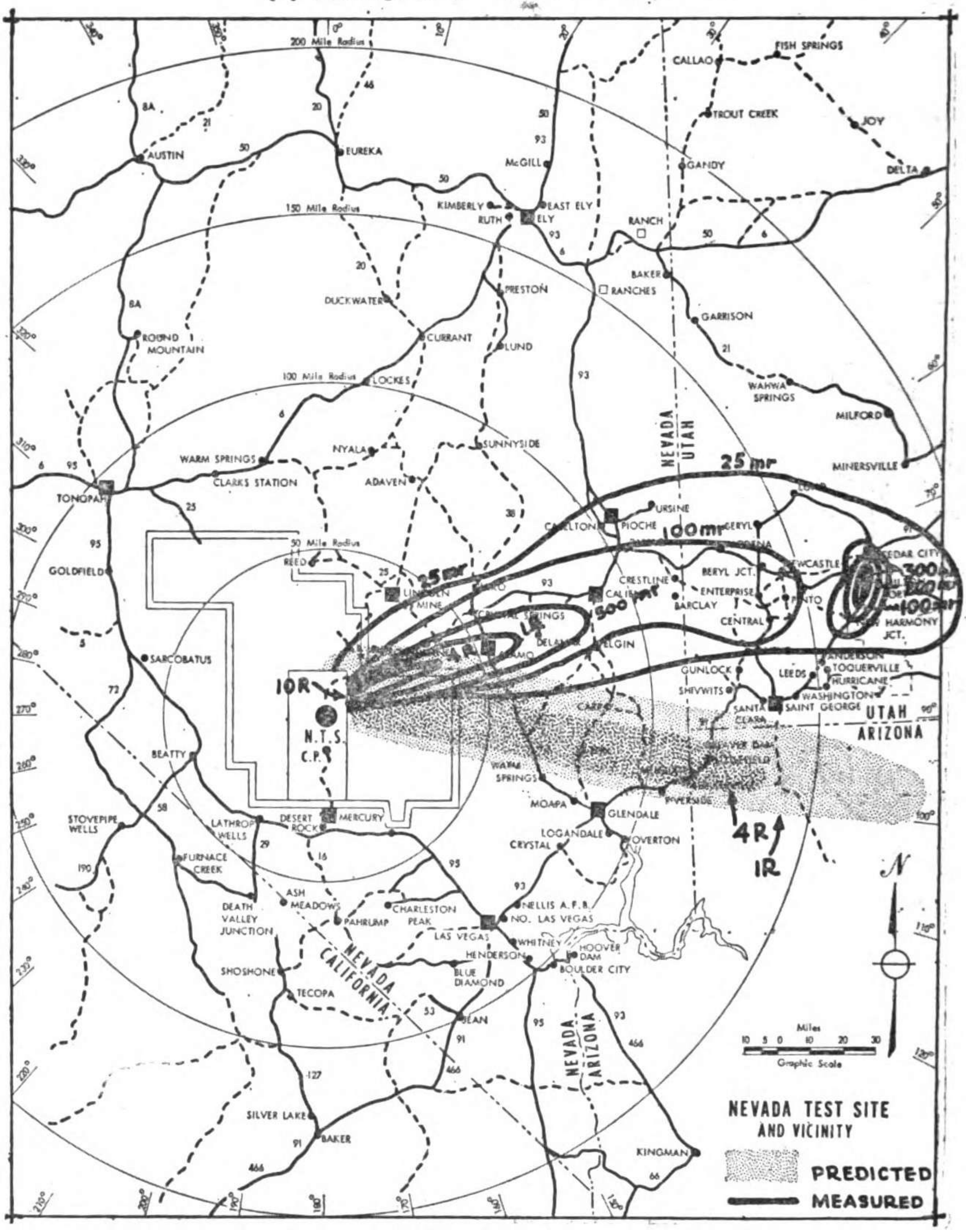
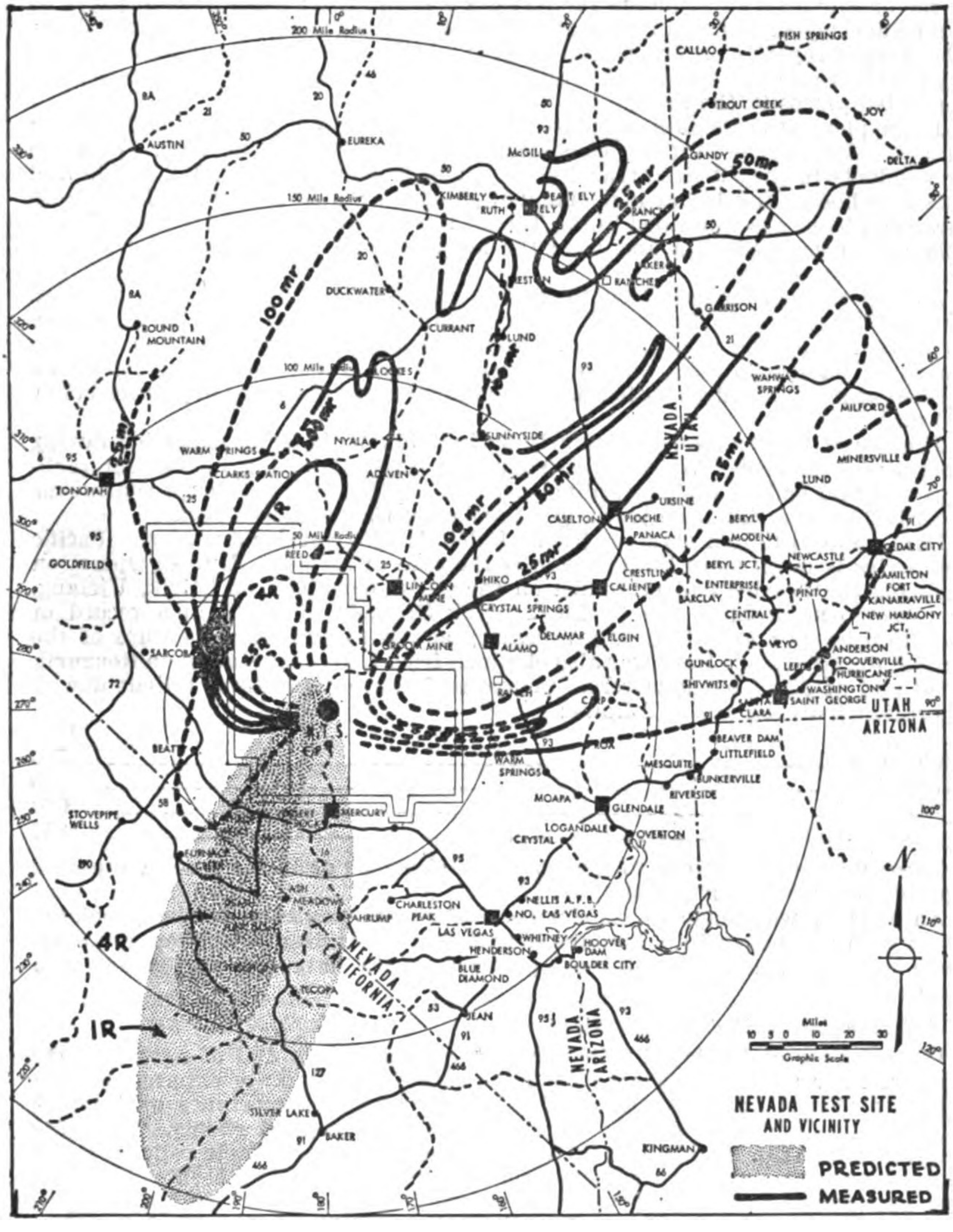


CHART 8

FALLOUT PATTERNS



Data from this report also indicates that cloud tracking with planes will generally give only an indication of the direction of fallout and cannot be relied upon for precise knowledge concerning deposition on the ground.[1] Most of the time it will give an idea of the direction from the point of detonation in which the fallout will occur, but this is not always the case. For public health emergency action it is not possible to depend entirely on cloud tracking as this will not always result in a reduction in exposure.

2. *Observed patterns of local fallout.*—A good deal of data has been obtained in the off-site area surrounding the Nevada test site from which fallout patterns can be developed. Charts I through III show such patterns for individual shots. The Teapot report contains a similar map which shows the cumulative fallout for the entire Teapot series and a tabulation of doses calculated in two ways for populated places in the area.[1]

To supplement these data calculated from meter readings, use was made of film badges.[1] Film-badge stations consisted of the following categories: 171 worn by residents in the off-site area; 106 posted in populated areas; 152 inside and outside schools; and 126 at nonpopulated points in the off-site area. Data from these film badges is contained in the Teapot report. In general they agree favorably with computed data and have the advantage of comprising a permanent record of exposures.

A comparison of the data from the film badges indicate that the dosage received by inhabitants in a particular area is less than the dose indicated for that area as measured by the same method. Approximately 94 percent of the dosages measured on people were within the 0 to 100 mr. range while only about 57 percent of the film badges posted in the populated areas indicated exposures below 100 mr.[1]

The use of film badges, particularly on individuals, is being expanded during Operation Plumbbob. We are also supplementing monitoring instrument readings and film badges with recording instruments that will give us a continuous record of gamma radiation levels in a number of the populated areas.

Data on local fallout obtained by the Public Health Service during any Pacific test series is much more limited than is the case in Nevada. During Operation Redwing the Service had personnel on the populated atolls of Utirik, Ujelang, and Wotho adjacent to the Pacific Proving Grounds to maintain a record of radiation levels and initiate any necessary action to minimize exposure of the natives to radiation.[2] Data was also obtained from a weather station on Rongarik Atoll and at JTF7 headquarters. Computed infinite doses from fallout due to Operation Redwing are as follows:

	Mr.
Ujelang Atoll	560
Utirik Atoll	50
Wotho Atoll	620
Rongarik Atoll	850

These figures are subject to the same qualifications as in the case of reported figures from Operation Teapot.

An attempt was made to supplement instrument readings on the populated atolls with film-badge data, but, due to technical difficulties which were not overcome until near the end of the operation, these data are incomplete and inconclusive.[3]

C. Intermediate and delayed fallout

Intermediate and delayed fallout are at concentrations and of ages to make them of little or no significance from the standpoint of acute external gamma exposure effects, but make them of relatively greater importance as internal beta emitters and with respect to the long-range biological effects. With the assistance of AEC, in 1956 and 1957, a routine system of sample collection and reporting in cooperation with State departments of health has been established. Our nationwide radiation surveillance network measures beta activity of particulates collected from air samples. Data from this network may be used to indicate the concentrations of radioactive materials which could expose humans to direct and indirect internal radiation hazards. Daily ambient gamma readings are also taken on a Geiger counter type of survey instrument.

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[1] See footnote, p. 328.

[2] Unpublished report, Radiation Exposures Received on Populated Atoll as a Result of Operation Redwing.

[3] Unpublished report, Report on Experimental Film Badge Study During Operation Redwing.

Two references describe the collection and measurement of radioactivity deriving from the troposphere.[4 5] The Public Health Service, for a number of years, has been developing methods which assist the States in determining environmental radiation levels and interpreting those data in terms of Public Health significance.

Reference 4 summarizes the results of this operation and demonstrates the increasing amounts of fallout found in the United States from our, and foreign, nuclear tests. Reference 5 presents a more detailed study, principally in relation to rainfall, in the Cincinnati, Ohio, area.

Radioactivity in air, at any one location, is a daily variable and cannot quantitatively be predicted from a knowledge of test schedules. For public health evaluation there appears to be no substitute for routine measurement techniques. Deposition on the ground, to a large degree, is related to rainfall. Distribution of radioactivity, geographically, is then largely dependent upon local topography and meteorology. Rainfall may contain much more activity than do the surface waters which are fed by the rainfall. The protective factors offered by the watershed may give as high as 90 percent removal of gross radioactivity.

Fallout from many nuclear tests is now always present in the air we breathe and the water supplies for ourselves, our animals, and our plants. Since there are many variables it is necessary to make measurements and keep records on those factors in the environment which directly affect man in order to make a public health evaluation of the hazards.

VII. LOCAL FALLOUT: THE MECHANISMS BY WHICH IT CAN AFFECT MAN AND THE MEASURES HE CAN TAKE TO MINIMIZE EXPOSURE

B. Shelter and shielding and their effects

By the nature of the radiation involved, it has been observed that persons can protect themselves from the acute, external effects of the beta component of fallout simply by staying under cover at the time of fallout so that none or little falls on them. Virtually direct contact with the skin is necessary to produce beta burns. We have also observed that remaining in a building will provide some protection from gamma radiation as a result of the shielding effect of the structure and the distance from the fallout afforded by being in the building.

Some data on the gamma exposure protection afforded by this means was obtained during Operation Teapot by placing film badges inside and outside of school buildings.[1] A tabulation of the results is given in the Teapot report.

The significant feature of this data is the apparent protection offered by the school buildings. The upper exposure limit is reduced by a considerable factor on a gross basis and while about 95 percent of the inside exposures fall within the 0–100 mr range, only about 79 percent of the outside badges are below 100 mr.

During Operation Plumbbob the Service is going to attempt a much more complete documentation of the shielding effects of buildings. Film badges will be placed inside and outside of several different types of buildings and at several locations within the buildings. Film badge data will be supplemented insofar as possible with data from recording instruments which will give a continuous plot of time versus intensity of gamma radiation.

C. Other immediate emergency measures that can reduce hazard

The Public Health Service has operated under radsafe criteria in the Pacific and in Nevada which illustrate the type of emergency action which may be taken in the event of unexpectedly heavy fallout.[1 6] These were devolped jointly with JTF7 and the Nevada test organization respectively.

Both of these criteria recommend remaining indoors or under cover during periods of fallout to avoid direct contact with falling or settling radioactive particles. If exposed to fallout, personal decontamination is recommended including dusting and shaking off or laundering clothes and bathing with particular attention being given to washing under the arms, the groin, face, and hair. Covering of food and water to prevent ingestion of fallout particles is recommended.

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[4] A Brief Review of the Public Health Service Radiation Surveillance Network, May 22, 1957.

[5] The Distribution of Radioactivity From Rain, by L. R. Setter and C. P. Straub, presented at the American Geophysical Union Meeting, April 29–May 1, 1957, Washington, D. C.

[6] Radsafe Emergency Instructions for Populated Islands.

An emergency measure recommended in the Pacific is to stand in the lagoon immersed as far as possible in the water while continuing to wash off exposed portions of the body. This recommendation is based on the fact that the fallout settles from the surface and allows water to attenuate the radiations. This fact has been checked in the field by PHS personnel.

In extreme emergencies, evacuation of contaminated areas may be indicated. This procedure is practical only if the evacuation will result in lower exposures than would result by staying within a shelter and if the location and intensity of the fallout pattern is known so that persons will, in the least possible time, be moved to areas of lesser contamination rather than into an area of higher contamination.

D. Dose and dose-rate versus time

During Redwing the PHS collected data at intervals ranging from once daily to once each hour with a gamma survey instrument at each of the atolls of concern.[3]

This data shows a phenomenon that has not, to our knowledge, been discussed to any great extent and that is the fact that, in the case of the larger weapons, the arrival of fallout may be extended over a period of several hours. Thus, although the fission products are decaying, this not apparent because of the continued arrival of new fallout. Typically, the radiation intensity will build up quite rapidly to a maximum, remain at or near this maximum for a period of several hours, and then start to decrease slowly. Thus a significant amount of exposure may be received before apparent decay starts.

VIII. DELAYED FALLOUT

A. The relative importance of internal emitters compared with external radiation in general for the long-run fallout situation

Elsewhere in our presentation mention has been made of the Public Health Service surveillance programs for air, water and milk. From the data which the Service has collected, and from other published information, we are following the obvious conclusion that, especially in relation to fallout, we must develop the trends of the amounts of internal emitters in man's environment and in his food chain. Because of the masking effect of natural background, external exposure effects relatable to fallout appear to be small in long-term potential when compared to the probabilities of accumulative buildup of internal emitters.

B. Deposition on and migration in soil and transport by surface waters

A number of Public Health Service studies are directly associated with the problems of migration and transport. Specific reference is made to the cooperative studies on high level radioactive waste performed by our staff from the Robert A. Taft Sanitary Enigineering Center at Oak Ridge National Laboratory.[7]

In relation to the problem of transport in surface waters, background and operational studies made by the PHS at the Columbia and Savannah River systems have a direct bearing, and provide research support data.[8 9]

D. The effect of fallout on water supplies for human, agricultural, and industrial use

The Public Health Service has studied efficiency of normal water-treatment methods for the removal of radioisotopes from water supplies, and has made observations on the natural protective mechanisms.[10]

Depending, of course, on the exact nature of the radioactive compounds water-treatment methods offer limited protection. The degree of protection is on the order of 10 percent to 98 percent removal, or a decontamination factor ranging from 1.1 to 50.

The protective factors found in nature such as removal in watershed areas, are also within this range.[5] We have observed that in order to achieve removals of a much higher degree, as might prove necessary in the event of massive fallout during time of war or nuclear accident, the potential cost of effective water

[7] ORNL 1684, Radioactive Waste Disposal Research, by R. J. Morton et al., sec. I–60, Health Physics Division Semiannual Program Report, for period ending January 31, 1954.

[8] Columbia River Studies.

[9] Interim Report on the Savannah River Studies, July 1951–July 1952. U. S. Department of HEW, Public Health Service, 1954.

[10] Limitations of Water Treatment Methods for Removing Radioactive Contaminants, by C. P. Straub, Public Health Reports, No. 70, 897 (1955).

treatment, such as ion exchange removal, increases tremendously. The requirements in treatment materials in quantity alone is probably prohibitive. At the present time we cannot state that modern water-treatment methods applicable to the general population offer substantial protection against fallout.

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2. Unpublished report, Radiation Exposures Received on Populated Atolls as a Result of Operation Redwing. (See p, 441.)

3. Unpublished report, Report on Experimental Film Badge Study During Operating Redwing. (See p. 452.)

4. Unpublished report, Brief Review of the Public Health Surveillance Network, May 22, 1957. (See p. 459.)

5. The Distribution of Radioactivity From Rain, by L. R. Setter and C. P. Straub, presented at the American Geophysical Union meeting, April 29–May 1, 1957, Washington, D. C. (See p. 466.)

6. Radsafe Emergency Instructions for Populated Islands, JTF–7. (See p. 475.)

7. ORNL 1684, Radioactive Waste Disposal Research, by R. J. Morton, et al., section I–60, Health Physics Division semiannual progress report for period ending January 31, 1954.

8. Columbia River Studies.

9. Interim Report on the Savannah River Studies, July 1951–July 1952, United States Department of Health, Education, and Welfare, Public Health Service, 1954.

10. Limitations of Water Treatment Methods for Removing Radioactive Contaminants, by C. P. Straub, Public Health Reports, No. 70, 897 (1955).

11. The Detectability of Low-Level Radioactivity in Water, by A. S. Goldin, J. S. Nader, and L. R. Setter, Journal American Water Works Association, volume 45, No. 1, January 1953.

12. Measurement of Low-Level Radioactivity in Water, by L. R. Setter and A. S. Goldin, Journal American Water Works Association, volume 48, No. 11, November 1956.

13. Unpublished office memo on Measurement of Radioactivity in Water, Bottom Silts, and Biological Materials, by J. E. Flanagan, Jr., January 30, 1957.

REPORT OF OFF-SITE RADIOLOGICAL SAFETY ACTIVITIES—OPERATION TEAPOT, NEVADA TEST SITE, SPRING, 1955

Prepared for the Test Division, Santa Fe Operations Office, United States Atomic Energy Commission; prepared by J. B. Sanders, Branch Manager, Las Vegas Branch Office, AEC; O. R. Placak, Off-Site Radiological Safety Officer, PHS; M. W. Carter, Deputy Off-Site Radiological Safety Officer, PHS

PURPOSE

The purpose of this report is to present a concise summary of off-site rad-safe activities during Operation Teapot and to serve as a source of information to interested AEC and health agency personnel. All pertinent data necessary to evaluate the exposure effects of the operation in populated areas are included. In the interests of brevity, selected data only are given for nonpopulated areas. Complete monitoring logs and detailed film badge results covering these areas are, however, available from the files of the Las Vegas Branch Office, AEC.

PLAN OF REPORT

This report is composed of the following general sections:

1. AEC radiological criteria for the protection of the public.
2. Off-site Rad-Safe Organization.
3. Methods and equipment used.
4. Public relations.
5. Résumé of individual shots are also included.

These individual sections cover the following materials: A summary of monitoring runs and dosages, airway closures, cloud tracking, and low-level terrain

surveys; a table which includes the dosages at all populated places where the external gamma dosage rate reading was greater than 0.1 mr/hr. and selected values in nonpopulated areas such as the maximum dosage and the dosage at points where the fallout crossed main highways; maps of fallout prediction, cloud tracking, low-level terrain survey, and ground-survey data.

6. Summaries.

In addition to the above, the following summaries and maps are included:

Integrated dosage for populated areas.
Film-badge data.
Milk-sampling data.
Water-sampling data.
Air-sampling data.
Maps: Integrated dosages from survey data.

1. AEC RADIOLOGICAL CRITERIA FOR THE PROTECTION OF THE PUBLIC

The Division of Biology and Medicine accepted the responsibility for establishing such criteria and procedures as were deemed necessary by the Atomic Energy Commission to protect the health and welfare of the general populace from the consequences of tests at the Nevada test site. The operational procedures adopted during Operation Teapot to meet these criteria were the responsibility of the Test Manager and were carried out by the Off-Site Rad-Safe Organization, under the direct supervision of the Support Director.

The basic criterion was that the whole-body gamma effective biological dose (EBD) for the off-site population should not exceed 3.9 roentgens over a period of 1 year. This total dose may result from a single exposure or a series of exposures.

The effective biological dose is an estimate of the biological damage dose taking into account the length of time for delivery of a given dose and the reduction of dose due to (*a*) shielding afforded by buildings, and (*b*) the process of weathering.

The EBD, as computed from integrations of dose rate readings, is the sum of three-fourths of the maximum theoretical radiation dose from time of fallout to 15 days later and one-half of the maximum theoretical dose from the 15th day to 1 year.

Values of gamma dose rate readings that will satisfy this criterion for particular situations are given in graphs I, II, and III.

Personnel should be requested to remain indoors with windows and doors closed when the gamma dose rate reading, measured by a survey meter held 3 feet above ground, reaches the values given in graph I at the times indicated.

Personnel decontamination should be practiced when the gamma dose rate readings, measured by a survey meter held 4 inches from the contaminated area, equals or exceeds the values given in graph II.

Vehicles should be cleaned inside and out when the gamma dose rate readings, measured by a survey meter held 4 inches from the surface, equals or exceeds the values given in graph III.

It is recommended that when the predicted fallout across a main highway will be equivalent to a 10 roentgen infinity gamma dose or higher, that vehicles will be held until after fallout has essentially ceased.

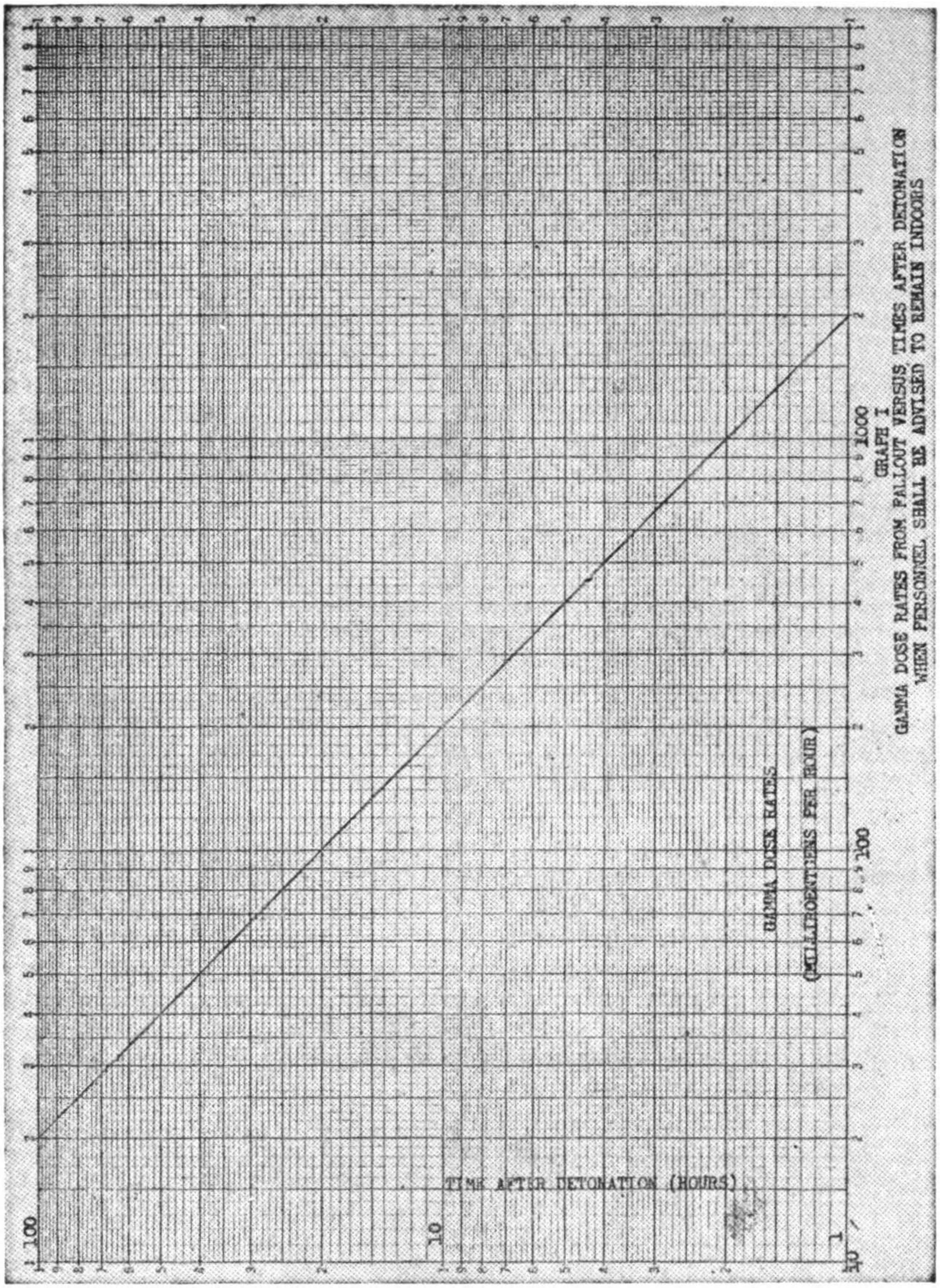
The above criteria do not apply to domestic or wild animals since levels of radiation which would be significant to them would have to be higher than those specified.

A more complete discussion of criteria is contained in a Division of Biology and Medicine, AEC, publication entitled "Atomic Energy Commission Radiological Safety Criteria and Procedures for Protecting the Public During Weapons Testing at the Nevada Test Site" dated February 1955.

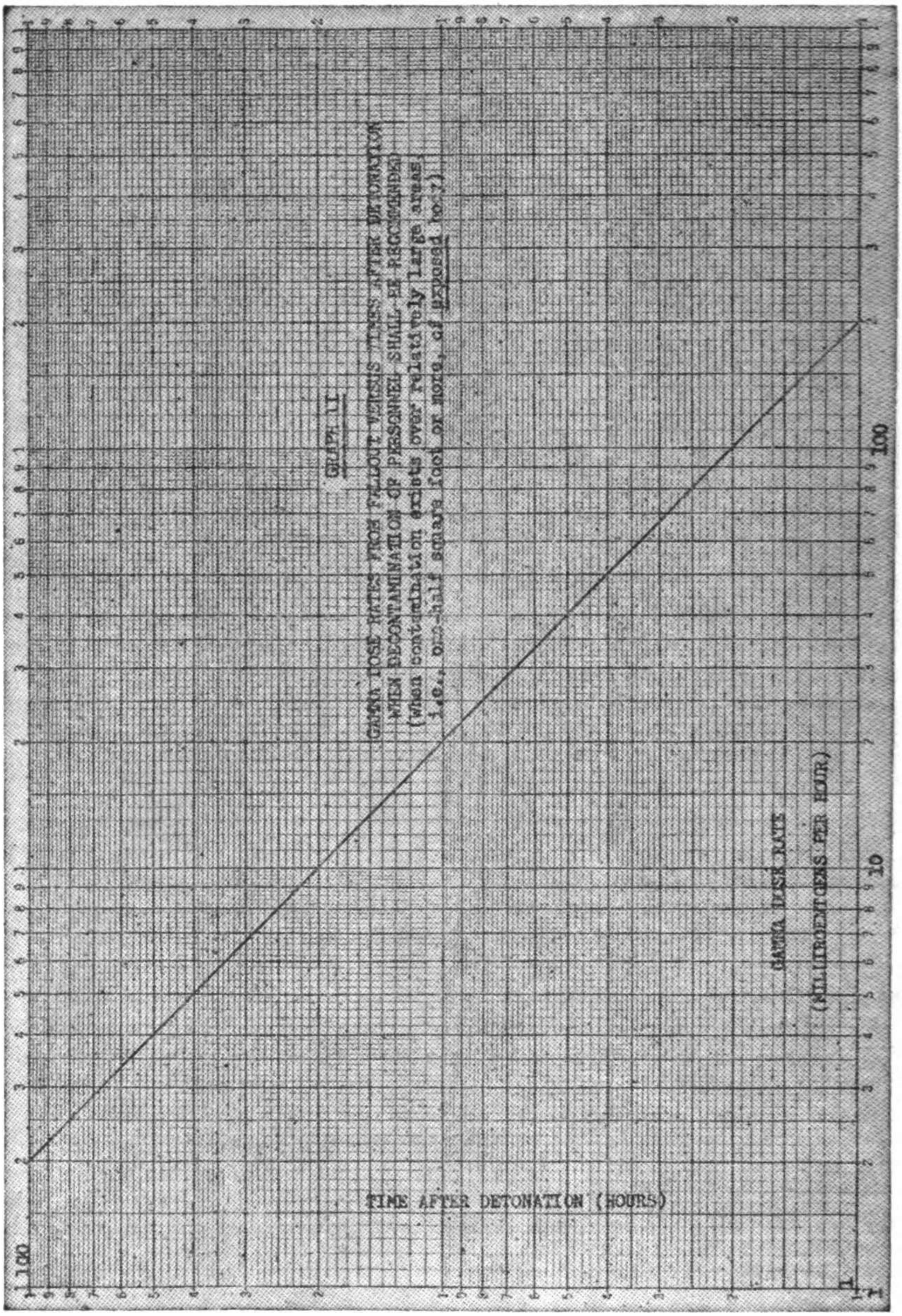
2. OFF-SITE RAD SAFE ORGANIZATION

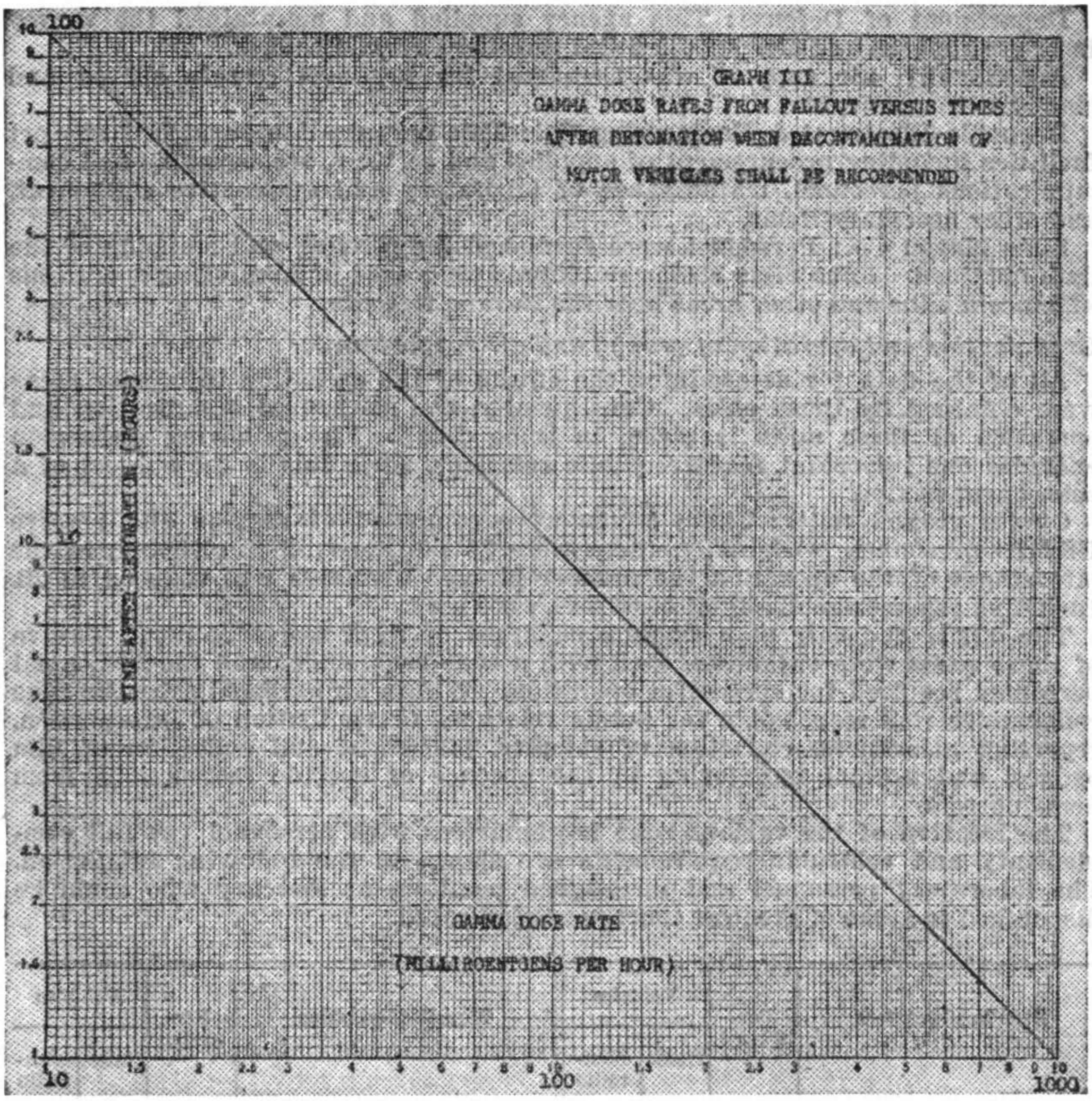
Off-site rad safe operations were a responsibility of the Test Manager and the Support Director, and were directed by the Deputy Director for Support, who was the Off-Site Operations Chief, and the PHS officer in charge, who was the Deputy Off-Site Operations Chief.

The various functions of the Off-Site program as outlined in the scope of work immediately following were carried out by personnel from the AEC, PHS, DOD, Reynolds Electrical and Engineering Co., and Silas-Mason Co.



GRAPH I
GAMMA DOSE RATES FROM FALLOUT VERSUS TIMES AFTER DETONATION
WHEN PERSONNEL SHALL BE ADVISED TO REMAIN INDOORS


GRAPH LI
GAMMA DOSE RATES FROM FALLOUT VERSUS TIMES AFTER DETONATION
WHEN DECONTAMINATION OF PERSONNEL SHALL BE RECOMMENDED
(When contamination exists over relatively large areas
i.e., one-half square foot or more, of exposed body)
GAMMA DOSE RATE
(MILLIROENTGENS PER HOUR)
TIME AFTER DETONATION (HOURS)
1
10
100
100



Scope of program

The off-site rad safe program dated January 10, 1955, was designed to accomplish the following objectives:

1. To accurately delineate the duration and extent of the fallout pattern as determined by ground surveys.
2. To verify the above by low-level terrain surveys using aerial monitoring.
3. To determine, by aerial tracking, the intensity and direction of the radioactive cloud.
4. To determine the actual exposures to people and livestock, by the above methods, by film-badge exposure records and by air, milk, and water samples.
5. To obtain data, at points close to the Nevada Test Site, to improve the formulae used in fallout prediction.
6. To conduct a continuing public relations and education program.
7. To record, map, and report the data obtained.

Responsibilities of various agencies

Atomic Energy Commission: The AEC was responsible for the overall administration of the program and of the work of other agencies outlined in more detail below. This includes policy decisions, budget requirements, procurement of materials and supplies, and all other support requirements.

Public Health Service: All ground monitoring crews were composed of regular and reserve PHS personnel with the exceptions noted under Silas Mason Co. and Los Alamos Scientific Laboratory employees W. S. Johnson and C. P. Skillern, who assisted in prior planning and during the first five shots.

This group was directly responsible for accomplishing the objectives set forth in items 1, 4, 5, 6, and 7.

Department of Defense: This agency supplied and maintained the survey instruments used and also supplied and processed all film badges.

Additionally, air support was furnished for low-level terrain survey and cloud-tracking purposes.

Reynolds Electrical & Engineering Co.: This organization furnished support facilities including procurement of supplies and services, stenographic and communications personnel, maintenance of laboratory and automotive equipment, and other necessary items.

Silas Mason Co.: Personnel were furnished for plotting and mapping of the data obtained. Four Silas Mason employees were used in monitoring operations at Lincoln mine and other areas near the Nevada test site.

Organization and operation of ground and air support units

All of the data for determining the effects of the operation in off-site areas were obtained by these units. Consequently, the method of organization and operation of these units is given, in some detail. The following discussion excludes one important feature, public relations, since this is the subject of a subsequent section.

Offsite ground units: These teams were composed of regular and reserve USPHS personnel. Originally, there were 38 positions filled, although in the late stages of the operation the number of men available was reduced to 20. Including replacements, a total of 66 men were used.

The offsite rad safe plan established areas of local responsibility. Twelve of these zones were organized, each with a zone commander and the additional personnel required for successful operation. Within an assigned area the zone commander was responsible for public relations, dissemination of information, reporting grievances, collection of samples, placement and collection of film badges, and normal monitoring in the absence of specific instructions from headquarters.

The location of the various zone headquarters with personnel (at full complement) and vehicular requirements are shown in the following tabulation. The laboratory personnel and unassigned monitors at Mercury who could be dispatched to areas of greatest concern are indicated.

Zone headquarters	Personnel	Vehicles		Zone headquarters	Personnel	Vehicles	
		Radio	Nonradio			Radio	Nonradio
1. Tonopah, Nev.	2	1	------	9. Caliente, Nev.	2	1	------
2. Mercury, Nev.	1	1	------	10. Pioche, Nev.	2	1	------
3. Las Vegas, Nev.	1	1	------	11. Ely, Nev.	3	1	1
4. Glendale, Nev.	2	1	------	Eureka, Nev.	1	1	------
Mesquite, Nev.	1	1	------	12. Lincoln mine (Tempiute), Nev.	2	1	1
5. St. George, Utah	2	1	------	Headquarters	4	1	------
6. Cedar City, Utah	2	1	------	Unassigned monitors at headquarters	4	4	------
7. Beaver, Utah	2	1	------				
8. Alamo, Nev.	2	1	------				

A complete roster of all off-site personnel is contained in appendix I.

Off-site communications were maintained by telephone and radio, telephones being used only when the radio network was not operating. This dual system of communications operated well and satisfactory contact with field personnel was maintained.

The radio net was composed of a net control station at Mercury, fixed and semifixed relay stations and mobile receiving and transmitting sets in the monitoring vehicles. The semifixed stations were mounted in trailers and could be relocated as required by a particular operation. The normal period of operation was from 0800 to 1600 each day. Operation subsequent to a shot was continuous until the all-clear announcement by net control.

The type, normal location, and personnel of the radio net at the start of the operation are given in the following tabulation.

Type station	Base station	Number of personnel
Control station	Mercury, Nev	2
Fixed	Currant, Nev	2
Do	St. George, Utah	2
Do	Lincoln Mine, Nev	2
Semifixed	Sunnyside or Warm Springs, Nev	1
Do	Glendale, Nev	2
Do	Alamo, Nev	2
Do	Caliente, Nev	2
Do	Pioche, Nev	2
Do	Ely, Nev	2
Do	Eureka or Geyser, Nev	2

A normal abbreviated sequence of events for ground monitoring operations follows:

Preshot:

1. Decision to proceed tentatively at evening weather briefing.
2. Field stations alerted—background samples started.
3. Radio stations and unassigned monitors dispatched as required.
4. Decision to proceed confirmed at early morning briefing.
5. Additional monitors dispatched as required.
6. Special preparations made, such as for roadblocks and evacuation.
7. Monitors advise people in their area.

Postshot:

8. All roads and populated areas in fallout area monitored as directed by headquarters.
9. All other monitors operate in manner prescribed in general instructions.
10. Monitoring of roads discontinued when no further information can be obtained.

D+1 following day:

11. Remonitoring performed as required.
12. Air samples, milk and water samples were collected as required.
13. Samples and data dispatched to laboratory for processing and counting.
14. Film badges collected as directed by headquarters.
15. Complaints and grievances investigated.
16. Field men continle public relations program.
17. Headquarters prepares report of the operation.

Off-site air support unit: This unit was staffed by Air Force personnel and including replacements was composed of approximately 20 airmen. The mission of the unit was:

1. To make low-level terrain surveys along the path of the fallout following a shot, and preshot reconnaissance surveys to check isolated areas for persons or animals.

2. To track the radioactive cloud or clouds at various altitudes and to record and plot the data obtained.

3. To assist the CAA in directing closure of airways in which a radiation hazard might develop based on preshot predictions and to recommend necessary changes based on actual cloud-tracking operation following a shot.

The aircraft assigned to the unit and their functional use are tabulated below. The detection devices used were T-1B and MX-5 type instruments. The air-to-ground conversion curve is shown as graph IV.

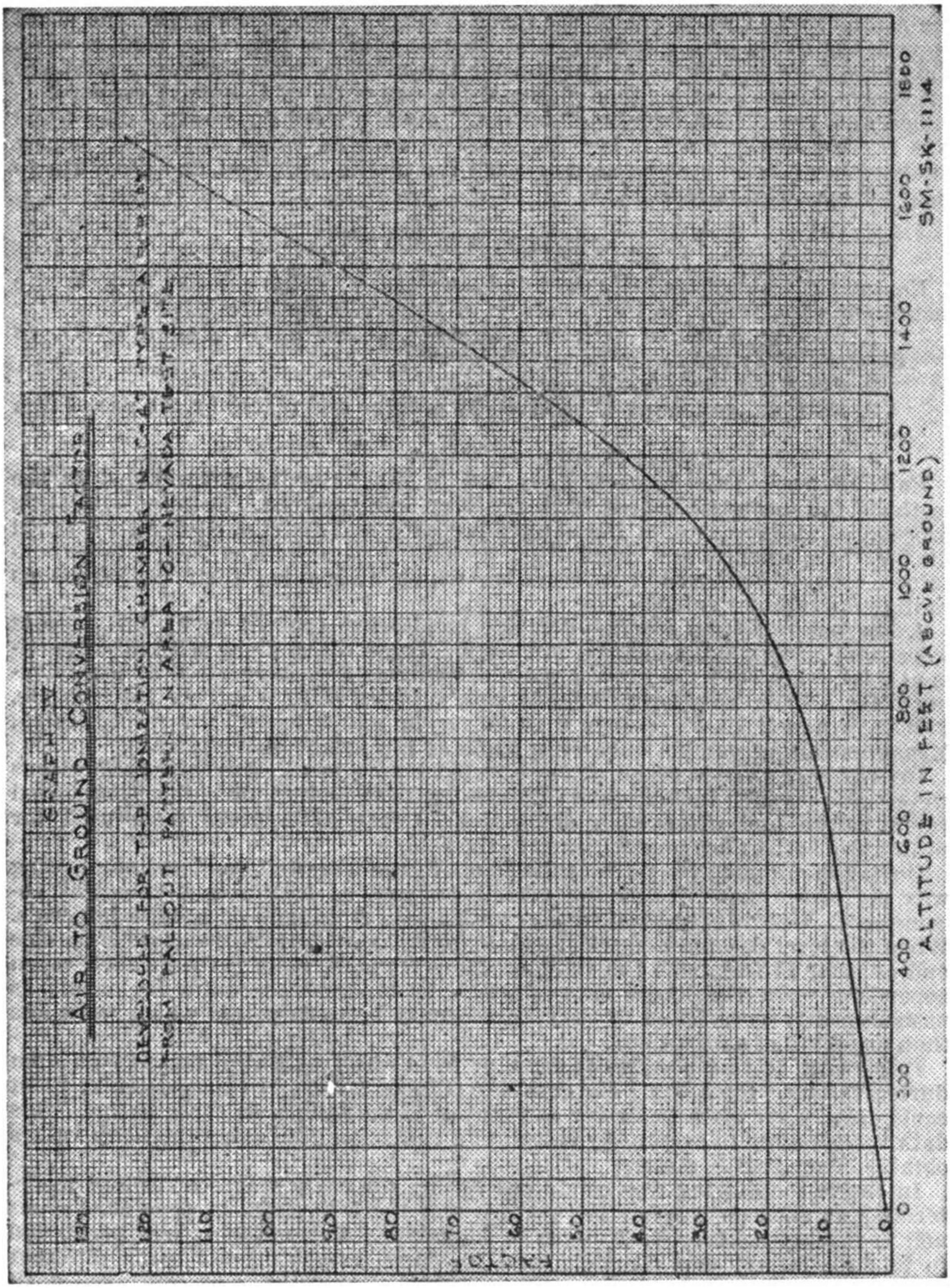
Type of aircraft	Number available	Use
C-47	2	Low level terrain surveys at 200 to 600 eet.
B-25	1	Cloud tracking, 10,000 to 15,000 feet.
B-29	1	Cloud tracking, 20,000 to 25,000 feet.
B-50	1	Cloud tracking, 27,000 to 32,000 feet.

A brief résumé of the technique of low level terrain survey and cloud tracking operations follows:

Low level terrain survey

Prior to the initial shot a terrain survey was conducted on D–1 for the purpose of locating persons and/or animals in the vicinity of the test site. On subsequent shots, the D–1 survey was conducted only upon request of the offsite operations chief or when reports indicated new concentrations or considerable changes in known livestock locations. Information was kept current by noting such positions whenever a low level survey of any type was flown.

On shot day, after sufficient time had been allowed for the fallout to occur, a low level mission was flown to delineate the fallout zones. To accomplish this mission, the aircraft was initially maneuvered to a point near ground zero to cross the suspected fallout zone at an angle of about 90°. From this starting point the fallout path was repeatedly crossed at altitude varying from 200 to 600 feet above the terrain, the interval between successive crossings varying from 3 to 10 miles, depending on the local terrain features. If possible, an altitude of about 300 to 500 feet above the terrain was maintained, since these proved to be the best operating levels for accurate readings on the radio altimeter. Since the conversion of the air reading of the radiac meter to a corresponding surface reading is dependent upon the altitude of the aircraft above the terrain, it was necessary that this factor be known as accurately as possible. In converting these readings, correlation curve (graph IV) was used. This curve was plotted from data obtained by flying a C–47 at various known altitudes above areas with known radiation intensities. The correlation between readings obtained by air surveys and those obtained by ground monitors was in reasonable agreement throughout the operation. The aerial survey proved invaluable in obtaining data in regions inaccessible to ground parties, thereby making it possible to more completely determine the actual fallout patterns.


GRAPH IV
AIR TO GROUND CONVERSION
FACTOR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
0
200
400
600
800
1000
1200
1400
1600
1800
ALTITUDE IN FEET (ABOVE GROUND)
SM-SK-1114

Cloud tracking

In order that the tracking aircraft could avoid deep penetrations of the cloud, the cloud was approached from one side at an angle of approximately 30° until a reading of 10 mr/hr or higher was obtained on the radiac meter. At this point the aircraft was turned out of the cloud as sharply as possible, and the cloud approached again at a different point, in this case the suspected leading edge. This procedure was repeated throughout the mission, with the result that the successive positions of leading edge and the two sides of the cloud were determined and provided a definite cloud track when plotted on a map. The cloud was tracked either until it had dispersed to such an extent that it no longer followed any particular direction or until the tracking aircraft had to return to base for operational reasons.

3. EQUIPMENT AND METHODS

Equipment was selected, located, and operated in such a manner as to insure maximum effectiveness in the collection of physical data pertaining to:

1. Surface levels of activity (normally, 3 feet above ground level), as determined by the use of survey meters.
2. Concentration of airborne activity.
3. External gamma dose received by persons and places by the use of film badges.
4. Activity contained in milk and water.

Each of these procedures is described in the following paragraphs, as the methods for sampling fallout have not been standardized. Detailed operating procedures along with data forms were prepared and distributed to all personnel during their briefing and orientation period. These written instructions contained general background information which augmented their usefulness as routine operational guides.

1. Surface radiation levels.—Portable monitoring (survey type) instruments were used to measure radiation intensity. These rates, along with other pertinent data, were then used to calculate the gamma dosage received at a particular point. Each monitoring vehicle was supplied with 4 survey instruments, 2 MX-5's and 2 T1-b's (range 0 to 20 mr/hr and 0 to 50 r/hr respectively). Measurements of gamma only were made at hip height above terrain.

Instruments were checked and calibrated before issue. Periodic calibrations were made on each instrument in the field with the minimum calibration period being before and after each detonation. Cobalt 60 sources were used for calibration both at headquarters and in the field.

During monitoring runs, the instruments in use were left "on" and monitoring was performed from inside the vehicle as long as background only was encountered. General readings were recorded at a maximum of 10-mile intervals. When the level encountered was twice background, monitoring was done outside and at least 25 feet from the vehicle. More frequent readings were then taken dependent upon the levels encountered. Distances were quite important as measurements were found to vary significantly between points which were less than one-tenth of a mile apart.

In general, it was possible to have at least one monitoring team in an area during fallout. Such being the case, the time of fallout at this particular point could then serve as a basis for estimating fallout times in other areas. This data is necessary to accurately calculate a radiation dose using intensity values obtained from survey meters.

Intensive monitoring was conducted during the early stages of fallout to determine as soon as possible the pattern and the intensities in populated areas and at strategic places such as major highways. Remonitoring was performed to be sure fallout was complete, and to obtain measurements using different instruments operated by different individuals. Monitoring was continued until it was thought no further useful data could be collected or because another detonation was imminently scheduled. It was necessary in a few instances to compromise slightly between completing today's shot activities and preparation for tomorrow's shot.

2. Airborne concentrations.—Staplex high volume air samplers were used with an MSA comfo-all dust filter for the collection of airborne contaminants. The rate of flow was in the range 1.1 to 1.3 cubic meters per minute. The standard sampling period was 28 hours beginning at shot time. Background samples, however, were run prior to each shot. The 28-hour sampling period included 7

APPLE TWO

Apple Two was a 500-foot tower detonation which was fired at 5: 10 a. m. on May 5, 1955. The shot took place in test area 1 in Yucca Flat.

The airway closure pattern was as follows:

1. A circular area around Yucca Flat, with a radius of 60 nautical miles, was ordered closed at all altitudes from 4: 45 a. m. to 9: 30 a. m. The southern half of this circle was to be opened at H plus 10 miutes.
2. A sector, radii at 315° and 20°, length of radius 140 nautical miles, was closed from 14,000 to 24,000 feet from 6: 30 a. m. to 9 a. m.
3. A sector, radii at 335° and 30°, length of radius 200 nautical miles, was closed from 24,000 to 44,000 feet from 6 a. m. to 10 a. m.
4. A continuation of this sector 3, above, extending the radius to 400 nautical miles, was closed from 24,000 to 44,000 feet from 8: 30 a. m. to 12 noon.
5. At 6: 30 a. m. the 30° bearing in sectors 3, and 4, was changed to 50°, and the extreme length of radius was reduced to 300 nautical miles.
6. At 8 a. m. the end closure time in 3. was changed to 12 noon, and the start closure time in 4. was changed to 9 a. m.
7. At 10 :10 a. m., sector 4. was opened at all altitudes.

Cloud track data were received from one B–25, two B–50's, and sampler aircraft. Maximum cloud height observed was 40,500 feet. Considerable shear was present and the various levels tracked showed a spread in bearing from about 340° to 60°. The cloud was tracked to a miximum distance of about 120 nautical miles at all levels. The plot of the several tracks is shown on the accompanying map.

A preshot survey was flown on D–3 days since the zone of predicted fallout was in a direction not extensively surveyed by air previously. A low level terrain survey was flown by one C–47 aircraft from H plus 5 hours to approximately H plus 10 hours and 30 minutes. Results of this survey are plotted on the accompanying map.

Monitoring runs, which indicated activity substantially above background, were made along U. S. 93 between 45 miles north of Pioche, Nev., and Ely, Nev.; on Nevada 25 between U. S. 6 and several miles west of Lincoln Mine, Nev.; on U. S. 6 between 1 mile east of Warm Springs, Nev., and Ely, Nev.: along Nevada 20 between Currant, Nev. and U. S. 50; on U. S. 50 between 55 miles west of Eureka, Nev., and Nevada 73; along Nevada 73 between U. S. 50 and Nevada 21; on Utah 21 between Nevada 73 and 25 miles east of Garrison, Utah; along Nevada 38 between Sunnyside, Nev., and 3 miles south of Sunnyside, Nev.; and along several of the desert roads north of the Nevada test site.

The maximum effective biological dose for a populated area was 2,580 mr. at Reed, Nev. The maximum effective biological dose at a nonpopulated point was 6,270 mr. in Kawich Valley northwest of the Nevada test site.

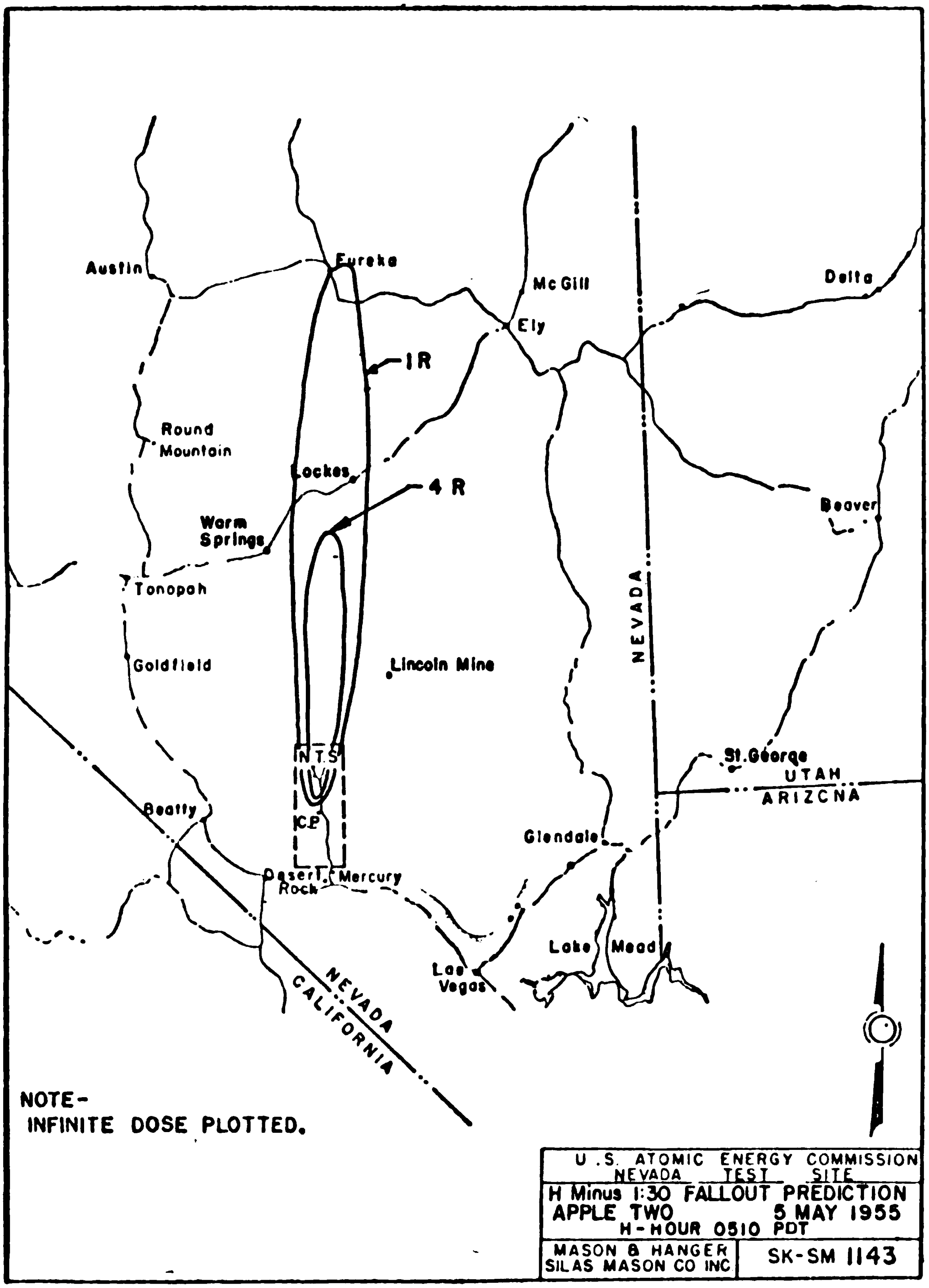
Approximately 385 individual monitoring readings above 0.1 mr/hr., were recorded.

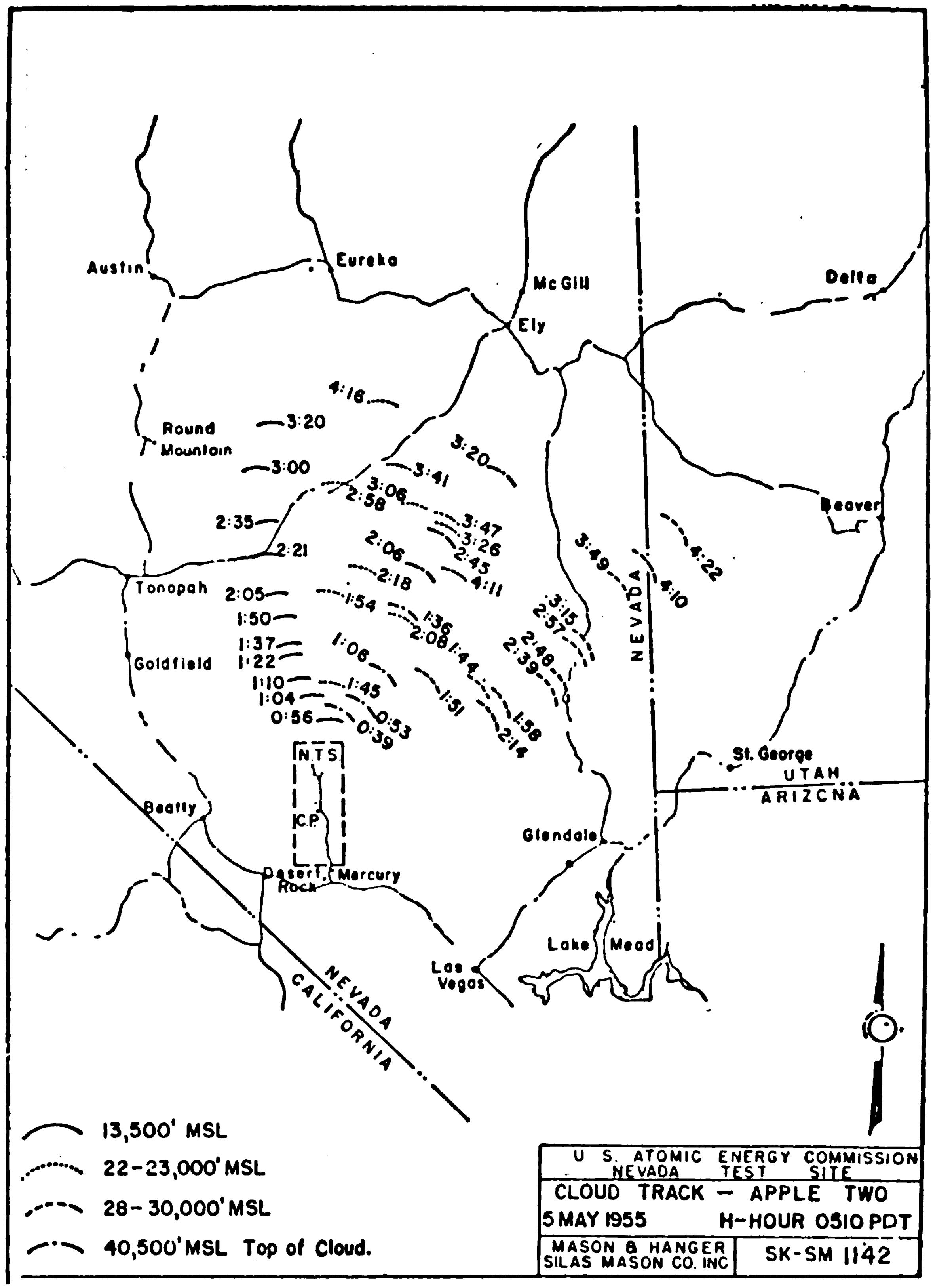
A comparison of the prediction map and the factual maps indicates good directional agreement with an overprediction in magnitude (length of isodose contours). The cloud track map shows one reason for the overprediction, and that is shear. The cloud was dispersed to a great extent laterally. The ground survey infinite dose map shows the 1 r. contour crossing U. S. 6 about midway between Tonopah and Ely, Nev. The shear, previously mentioned, is also evident in the construction of the isodose lines.

The maximum air radioactivity concentration measured was 5.9×10^{-3} $\mu c/m^3$, at Ely, Nev. This represents the average air concentration for a 28-hour period starting at shot time.

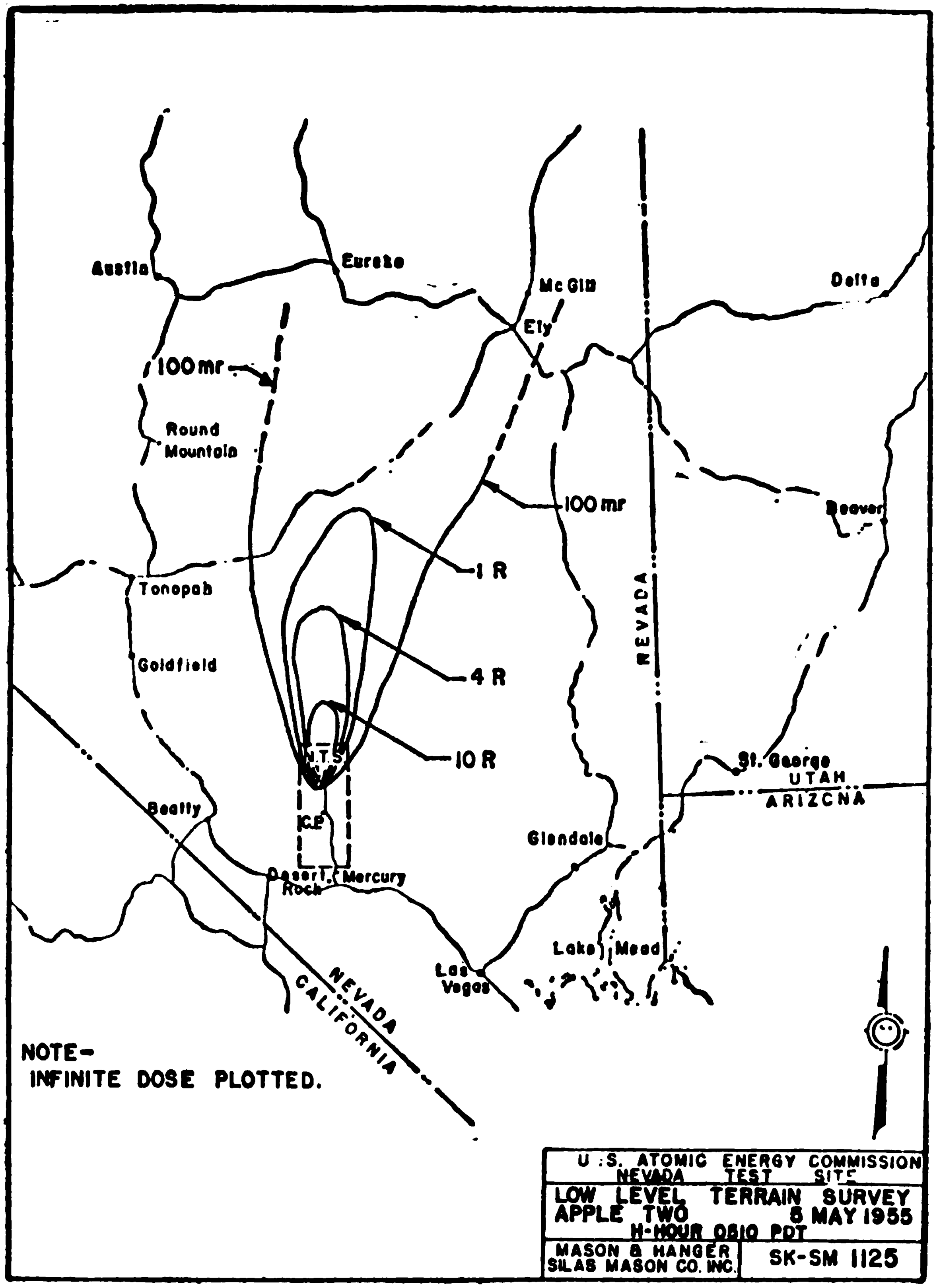
Apple Two: External gamma dose in populated areas and at selected nonpopulated points

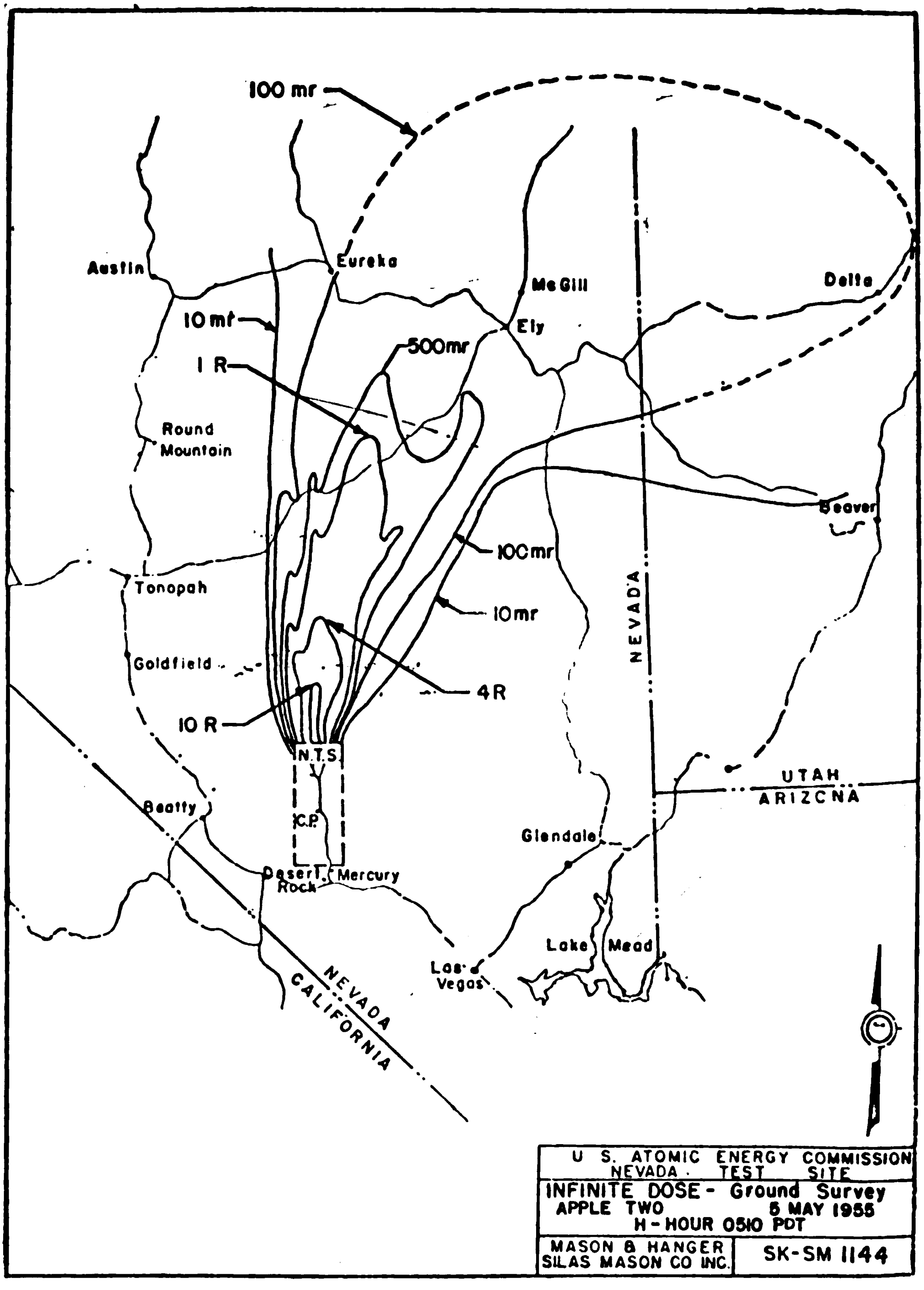
Location	Time of instrument reading (H+hours)	Gamma ground level (mr./hr.)	Time of fallout (H+hours)	Effective biological dose (mr.)	Infinite dose (mr.)
Populated areas:					
Adaven, Nev	4.2	18.0	4.1	200	370
Nyala, Nev	5.8	30.0	4.4	500	930
Lincoln Mine, Nev	15.0	.3	2.6	18	32
Fallini Ranch, Nev	5.0	13.0	4.2	250	460
Reed, Nev	6.8	110.0	2.5	2,580	4,590
Sunnyside, Nev	5.6	.4	5.6	5	10
Warm Springs, Nev	7.5	.3	4.2	6	11
Lockes Ranch, Nev	5.3	38.0	5.3	530	1,010
Currant, Nev	6.5	8.0	6.4	130	260
Duckwater, Nev	7.3	16.0	6.8	300	590
Lund, Nev	11.9	7.5	7.3	250	490
Ely, Nev	13.7	6.5	8.7	250	490
Baker, Nev	36.1	.8	9.1	95	190
Garrison, Utah	36.3	.5	9.0	60	120
Eureka, Nev	9.1	.8	9.1	18	36
Nonpopulated points:					
U. S. 6, 4 miles west of Lockes Ranch, Nev	5.4	55.0	5.3	790	1,490
Kawich Valley, Nev	4.2	440.0	1.8	6,270	10,900

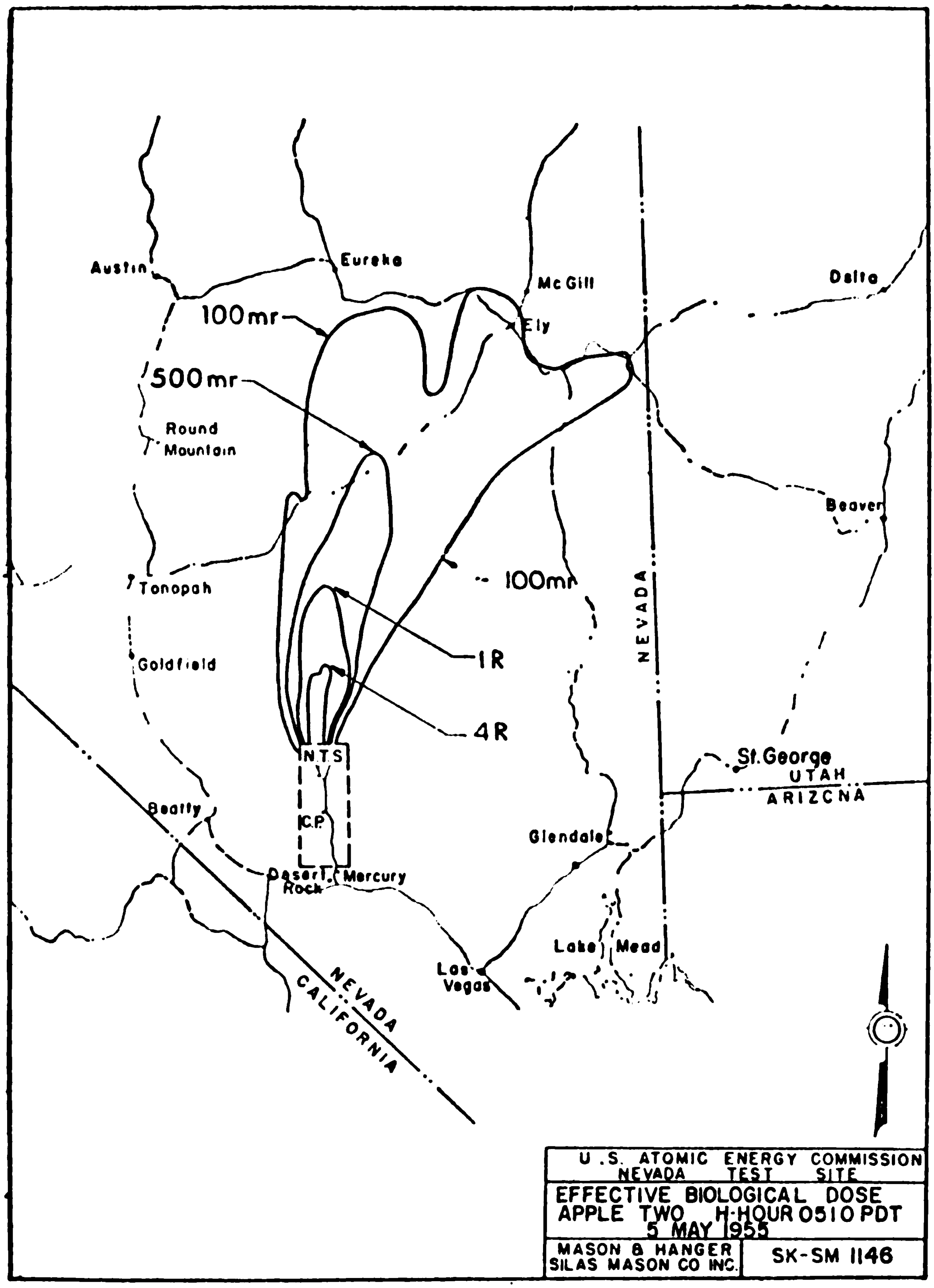

Austin
Eureka
McGill
Ely
Delta
1 R
Round
Mountain
Lockes
4 R
Warm
Springs
Beaver
Tonopah
NEVADA
Goldfield
Lincoln Mine
N.T.S.
St.George
UTAH
ARIZONA
Beatty
C.P.
Glendale
Desert
Rock
Mercury
Lake Mead
Las
Vegas
NEVADA
CALIFORNIA
NOTE-
INFINITE DOSE PLOTTED.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
H Minus 1:30 FALLOUT PREDICTION
APPLE TWO 5 MAY 1955
H-HOUR 0510 PDT
MASON & HANGER
SILAS MASON CO INC
SK-SM 1143



Austin
Eureka
McGill
Ely
Delta
Round Mountain
Tonopah
Goldfield
Beatty
N.T.S.
C.P.
Desert Rock
Mercury
Las Vegas
Glendale
Lake Mead
St. George
Beaver
UTAH
ARIZONA
NEVADA
NEVADA
CALIFORNIA
4:16
3:20
3:00
2:35
2:21
2:05
1:50
1:37
1:22
1:10
1:04
0:56
3:20
3:41
3:06
2:58
3:47
3:26
2:45
4:11
2:06
2:18
1:54
1:36
2:08
1:44
1:06
1:45
0:53
0:39
1:51
1:58
2:14
3:49
4:10
4:22
3:15
2:57
2:48
2:39
13,500' MSL
22-23,000' MSL
28-30,000' MSL
40,500' MSL Top of Cloud.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
CLOUD TRACK — APPLE TWO
5 MAY 1955
H-HOUR 0510 PDT
MASON & HANGER
SILAS MASON CO. INC
SK-SM 1142


Austin
Eureka
McGill
Ely
Delta
100mr
Round
Mountain
100 mr
Beaver
1 R
Tonopah
NEVADA
Goldfield
4 R
10 R
N.T.S.
St. George
UTAH
ARIZONA
Beatty
C.P.
Glendale
Desert
Rock
Mercury
Lake Mead
Las
Vegas
NEVADA
CALIFORNIA
NOTE-
INFINITE DOSE PLOTTED.
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
LOW LEVEL TERRAIN SURVEY
APPLE TWO 5 MAY 1955
H-HOUR 0510 PDT
MASON & HANGER
SILAS MASON CO. INC.
SK-SM 1125


100 mr
Austin
Eureka
McGill
Delta
Ely
10 mr
500mr
1 R
Round Mountain
Beaver
100mr
Tonopah
10mr
NEVADA
Goldfield
4R
10 R
N.T.S.
UTAH
ARIZONA
Beatty
C.P.
Glendale
Desert Rock
Mercury
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
U. S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
INFINITE DOSE - Ground Survey
APPLE TWO 5 MAY 1955
H-HOUR 0510 PDT
MASON & HANGER
SILAS MASON CO INC.
SK-SM 1144


Austin
Eureka
McGill
Delta
Ely
100mr
500mr
Round Mountain
Beaver
Tonopah
100mr
Goldfield
1R
4R
NEVADA
N.T.S.
St. George
UTAH
ARIZONA
Beatty
C.P.
Glendale
Desert Rock
Mercury
Lake Mead
Las Vegas
NEVADA
CALIFORNIA
U.S. ATOMIC ENERGY COMMISSION
NEVADA TEST SITE
EFFECTIVE BIOLOGICAL DOSE
APPLE TWO H-HOUR 0510 PDT
5 MAY 1955
MASON & HANGER
SILAS MASON CO INC.
SK-SM 1146

look at this (100 micromicrocuries) as the maximum permissible level. If it is a nonthreshold response we may look at this as an average level and try to decide what the risk is averaged over the entire population or averaged over any segment of the population.

What a nonthreshold response essentially says is that for every increment increase in dose there is an equal increment increase in effect and theoretically there is no maximum permissible level. There is an extremely small probability that any amount of radiation, the amount we wear on our wristwatches or the amount that we get from our natural potassium is going to harm somebody.

So the whole point of which of these numbers we can accept will depend upon our making a value judgment how much is atomic energy worth in cases of leukemia and bone cancer on a probability basis, averaged over the entire population or a certain segment thereof.

Senator ANDERSON. Thank you very much. I can say from personal acquaintance I know how long and hard you have worked in this field and I am very grateful to you for your testimony.

The next witness is Dr. Anderson.

Dr. ANDERSON. Mr. Chairman, I have nothing to add to the formal statement Dr. Langham made. I was in attendance only to answer questions.

Senator ANDERSON. Before we proceed with a discussion period with our several witnesses, there are several things that I would like to insert in the record at this point. First a statement by Wright H. Langham and Ernest C. Anderson. Next an article from Science Magazine, by Ernest C. Anderson, Robert L. Schuch, William R. Fisher, and Wright Langham, and finally a statement by L. D. Marinelli and J. E. Rose of the Argonne National Laboratory.

(The material referred to follows:)

SR-90 AND CS-137 IN RELATION TO THE PROBLEM OF WORLDWIDE RADIOACTIVE FALLOUT

By Wright H. Langham and Ernest C. Anderson, Los Alamos Scientific Laboratory, University of California, Los Alamos, N. Mex.

Although a number of isotopes are present in the fission mixture, the fallout of Sr-90 from weapons testing programs is the principal concern. Sr-90 is the most important isotope because of its similarity to calcium, long physical and biological half-time and high relative fission yield. These factors lead to high incorporation in the biosphere and a long residence time in bone. General contamination will result in the bones eventually reaching an equilibrium state with the Sr-90 in the biosphere.

Accepting Libby's postulation of three types of fallout (local, tropospheric, and stratospheric), levels as of the fall of 1956 were about 25 mc./mi.^{2} for the upper midwestern and northeastern sections of the United States, 16 mc./mi.^{2} for the section between 50° N. and 10° S. latitude, and about 4 mc./mi.^{2} for the rest of the world. These general values are variable, depending upon local rainfall and other meteorological patterns.

The observed levels of Sr-90 in bones of various ages are in good agreement with those calculated on the basis of a simple model of skeletal growth, remodeling and exchange. Using the data of Kulp for adults and children normalized to this model, an average equilibrium value of 3 μc. Sr-90/g. Ca is calculated for about 1975. Estimation of the equilibrium value from ecological discrimination factors suggests approximately the same average level. The normal spread of values for stable strontium and Sr-90 in human bones and for Cs-137 in people suggests that there is a very low probability that many people will show levels more than three times the average. On the basis of an equilibrium concentration of 3 μc. Sr-90/g. Ca resulting from detonations to date, about 18,000 megatons of fission could be injected at once into the biosphere before the average value would equal the maximum permissible level of 1,000 μc./g. Ca (the MPL for

industrial workers), and 1,800 megatons could be injected before reaching an average of 100 μc./g. Ca (the MPL for large areas of the population).

The above approach to the problem suggests (assuming no more weapons tests) that the average equilibrium level from weapons already tested may be about 3 percent of the MPL for the general population with a spread of from 1 to 9 percent. In terms of lifetime bone dose, these values are from 1/400 to 1/2,800 of the minimum dose from Ra 226, which has produced nonpathological bone changes. The biological significance of present and future predicted levels and whether average values may be applied to the general population depends on whether such chronic responses as bone sarcoma, leukemia, etc., to Sr–90 deposition are threshold or nonthreshold phenomena.

Estimates as to the number of megatons of fission that may be injected into the biosphere before Sr–90 becomes a serious health hazard to the general population vary by a factor of about 200. It is this variation in opinion that is responsible for much of the public confusion. Two factors that contribute a major portion of this wide uncertainty are:

1. The heterogeneity as to distribution of Sr–90 uptake in the skeleton as a function of diet and geographic location; and
2. Lack of information as to actual leukemogenic and tumorogenic response of man as a function of radiation dose.

Increased research effort to narrow the uncertainties in these two factors would seem to be desirable.

Measurements of present levels of Cs–137 in people indicate that it is of little significance in the potential hazard of radioactive fallout from weapons testing programs. Because of the chemical similarity of cesium and potassium, it is convenient to report cesium levels as Cs/K ratios. Potassium is an essential body constitutent and is itself naturally radioactive. The normal body potassium contribute 20 mr/year of the total natural yearly radiation dose of 100 mr. The present average Cs–137/K–40 total disintegration ratio is about 0.05. Taking into consideration their respective energies, the radiation dose from present levels of Cs–137 is only one-twentieth of that from natural K–40, or about 1 mr/year. This is about 1 percent of the average total natural radiation dose. The amount of Cs–137 now present in the population of the United States averages 0.006 μc., which is less than one-thousandth of the value given in the Recommendations of the International Commission for Radiological Protection as the maximum permissible level for the general population.

The short biological half-time of Cs–137 and its unavailability from soils will ensure that the levels in people will not continue to rise in the manner of Sr–90. The cesium levels will follow the rate of fallout and not integrated total accumulation.

Since Cs–137 does not show unusual concentration in the gonads, present levels in people will contribute only about 1 mr./year, or about 1 percent of the natural background level, to the genetic radiation dose.

The study of the distribution of Cs–137 should be continued to furnish information on fallout phenomena and to provide a measure of the rate of fallout and the amount of stratospheric storage, since this information might make considerable contribution to the solution of the Sr–90 problem.

[Reprinted from Science magazine, June 28, 1957]

RADIOACTIVITY OF PEOPLE AND FOODS

Ernest C. Anderson, Robert L. Schuch, William R. Fisher, Wright Langham[1]

The problems of widespread, low-level radioactive contamination from nuclear weapons testing have been increasingly before the public during the past year. The principal concern is the fallout and entry into the biosphere of strontium 90. There is general agreement that present levels of strontium 90 in foodstuffs and in the human body are far below the most conservative permissible amounts; however, the human burden of strontium 90 may be expected to rise as a result of deposition of stratospheric debris from weapons already (and subsequently to be) tested. Predictions based on conservative assumptions indicate that there remains a considerable margin of safety. If the rate

[1] Dr. Anderson, Mr. Schuch, and Dr. Langham are members of the biomedical research group at Los Alamos Scientific Laboratory, University of California, Los Alamos, N. Mex. Mr. Fisher, a former member of the group, is now at the University of Colorado School of Medicine, Denver.

of weapons testing continues to increase, however, this margin may eventually disappear.

Although the permissible levels contain inherent safety factors, it is essential that close attention be devoted to all aspects of the fallout problem during the next several years. Only in this way can advance notice of the possible approach to permissible levels be obtained and assurance given that they will not be exceeded inadvertently. Recent reports of the National Academy of Sciences-National Research Council Committee on the Biological Effects of Atomic Radiation (1) support the importance of systematic measurements of general levels of radioactivity in order that information on the rate of accumulation of extraneous radioactivities may be obtained while the latter are still below natural levels.

Large-scale production of nuclear power will create problems of a similar nature. A 100-megawatt (heat) reactor will, in one year of operation, produce the same quantity of long-lived fission products as the detonation of a 1-megaton fission bomb. The estimate of the United States nuclear power production rate by 1975 is 20,000 to 40,000 megawatts, and the United Kingdom expects to be producing 6,000 megawatts by 1965. Reactor-produced fission products constitute a much less immediate problem than those from a bomb test, since more control can be exercised over their immediate fate, but disposal of the fission products must eventually be made.

If disposal is to be simple enough to make nuclear power economically competitive, dispersal by natural means such as ocean burial or other means may have to be resorted to. This will increase the possibility that reactor-produced fission products may ultimately enter the food cycle and reach man. The basic problems of permissible body burdens and distribution mechanisms in the biosphere, therefore, are similar for bomb and reactor debris, and information gathered in the study of the former problems should prove valuable in the latter.

An extensive survey of strontium 90 levels (Project Sunshine) has been underway for several years, and the results have been reported by Libby (2–4) and by Kulp (5). Because strontium 90 and is daughter yttrium 90 emit only beta rays, analysis requires time-consuming and destructive chemical separations. Detailed studies of the temporal and spatial distribution of long-range fallout would be easier if they could be based on a gamma-emitting nuclide. The discovery of the presence of the fission product cesium 137 in human beings and in foodstuffs by Miller and Marinelli (6) provides a possibility of such an approach.

Similarity of the decay chains of the fission products of mass 90 and mass 137 indicates that distribution of cesium 137 and strontium 90 in bomb debris will be similar:

$$\text{Kr-90} \xrightarrow{33\text{ sec}} \text{Rb-90} \xrightarrow{2.7\text{ min}}$$
$$\text{Sr-90} \xrightarrow{28\text{ yr}} \text{Y-90} \xrightarrow{64\text{ hr}} \text{Zr-90 (stable)}$$
$$\text{I-137} \xrightarrow{19\text{ sec}} \text{Xe-137} \xrightarrow{3.4\text{ min}} \text{Cs-137} \xrightarrow{27\text{ yr}}$$
$$\text{Ba-137m} \xrightarrow{2.6\text{ min}} \text{Ba-137 (stable)}$$

Both nuclides have two gaseous or volatile predecessors with appreciable half-lives. Strontium 90 and cesium 137 are formed at relatively late times after bomb detonation and are not proportionally included in the larger and more refractory particles which fall out locally. Stratospheric storage and distant deposition will be high for both nuclides, and their ratio in distant fallout should be approximately that calculated from the known fission yields. Once strontium 90 enters the biosphere, its behavior becomes very complex. Its concentrations along the ecologic chain change slowly and reflect a summation of all past fallout. In addition, it enters plants both through the soil (in some relationship with available calcium) and by foliate absorption from direct fallout.

One very important and difficult problem is to determine the fraction of strontium 90 entering the ecologic chain by way of these routes. Cecium 137, however, is apparently poorly taken up from the soil by plants (7) and its biological half-times (8) are comparatively short (140 days in man (9) and 20 days in the cow (10)). These factors suggest that cesium in people and in milk and other foodstuffs may be a direct and relatively simple measure of fallout rate. One should be able, therefore, to make a direct determination of fallout rate as a

function of geographic location and time, as well as of changes in stratospheric storage following test operations, by measuring cesium 137 in biological materials. Cesium 137 measurements on soils might provide a more convenient method than strontium 90 measurements for estimating integrated fallout.

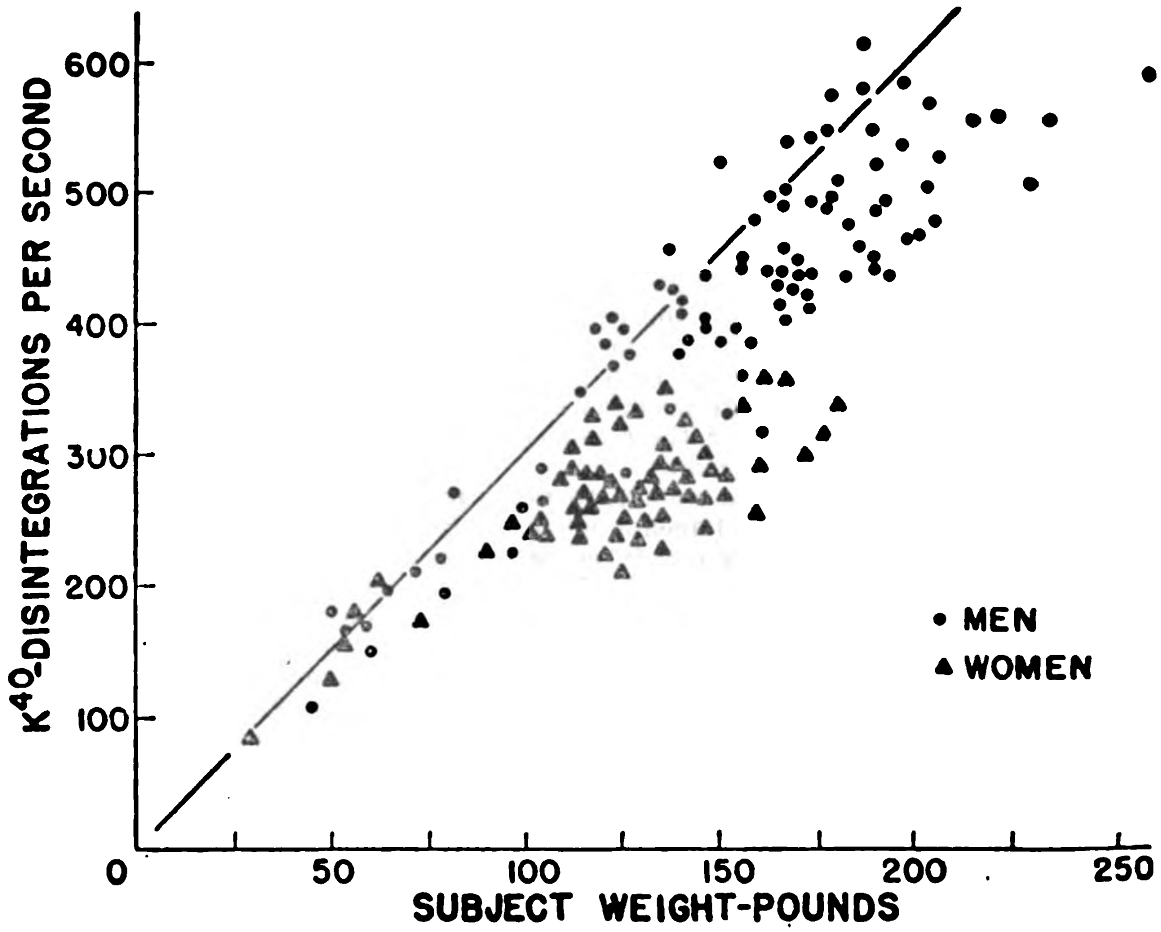


FIGURE 1.—Potassium 40 gamma activity in people as a function of gross body weight.

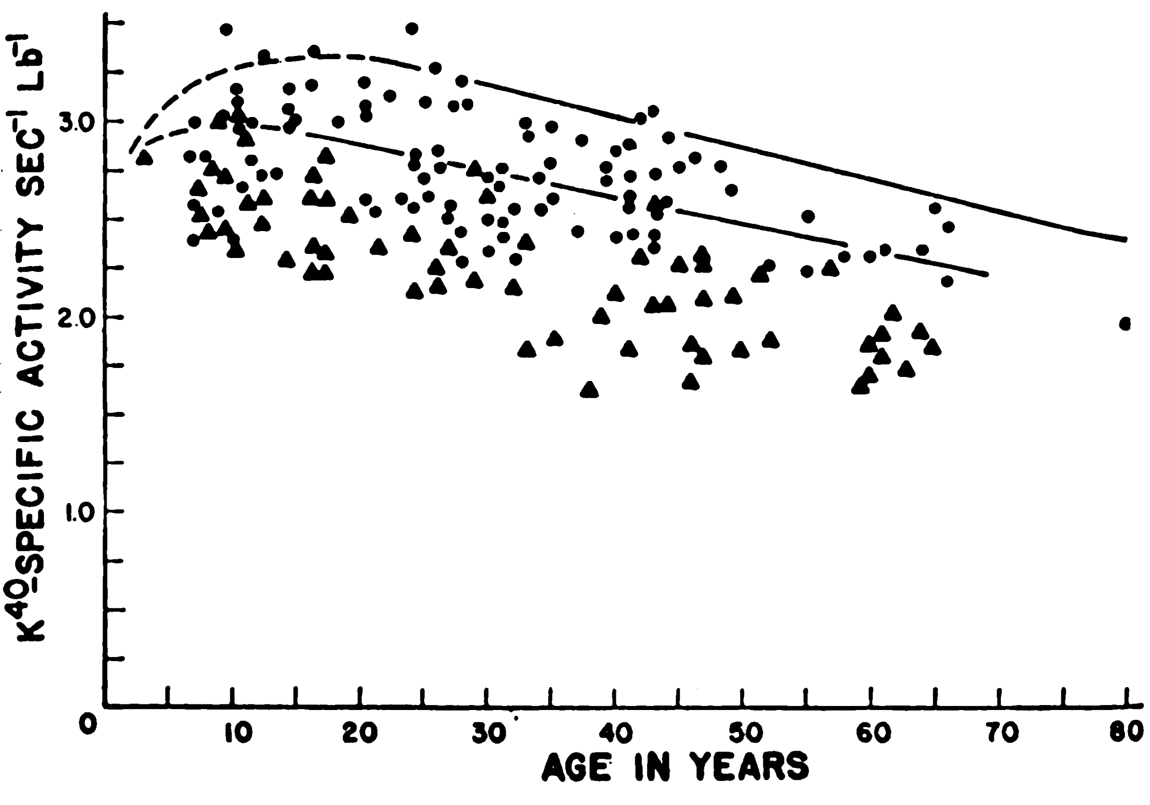


FIGURE 2.—Potassium 40 specific activity in people as a function of age.

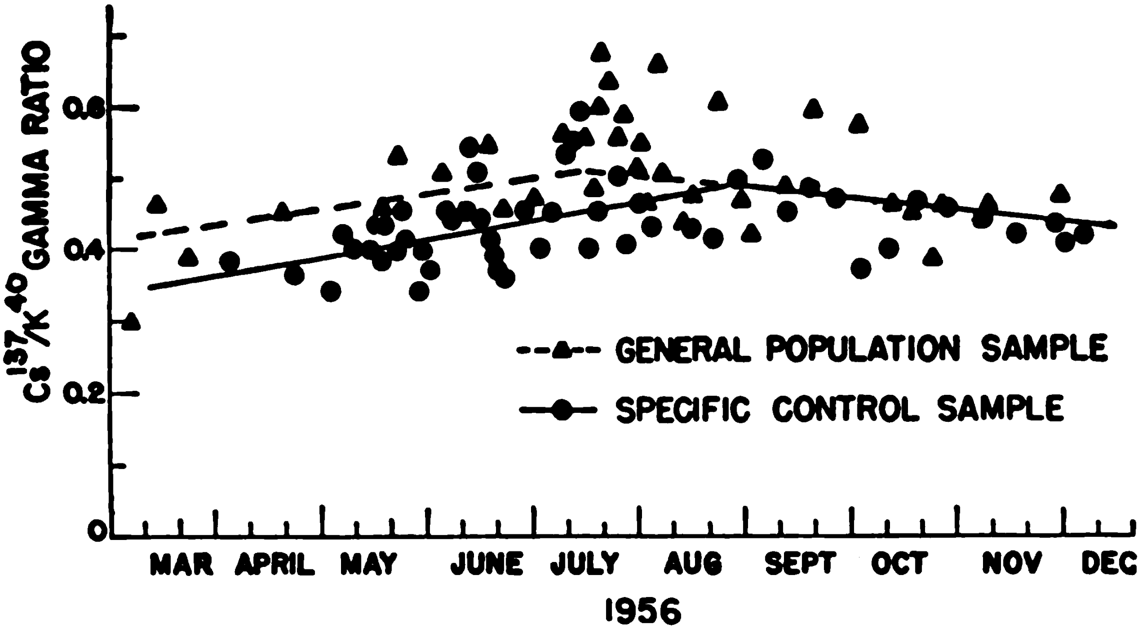


FIGURE 3.—Cesium 137/potassium 40 gamma ratio in people during 1956.

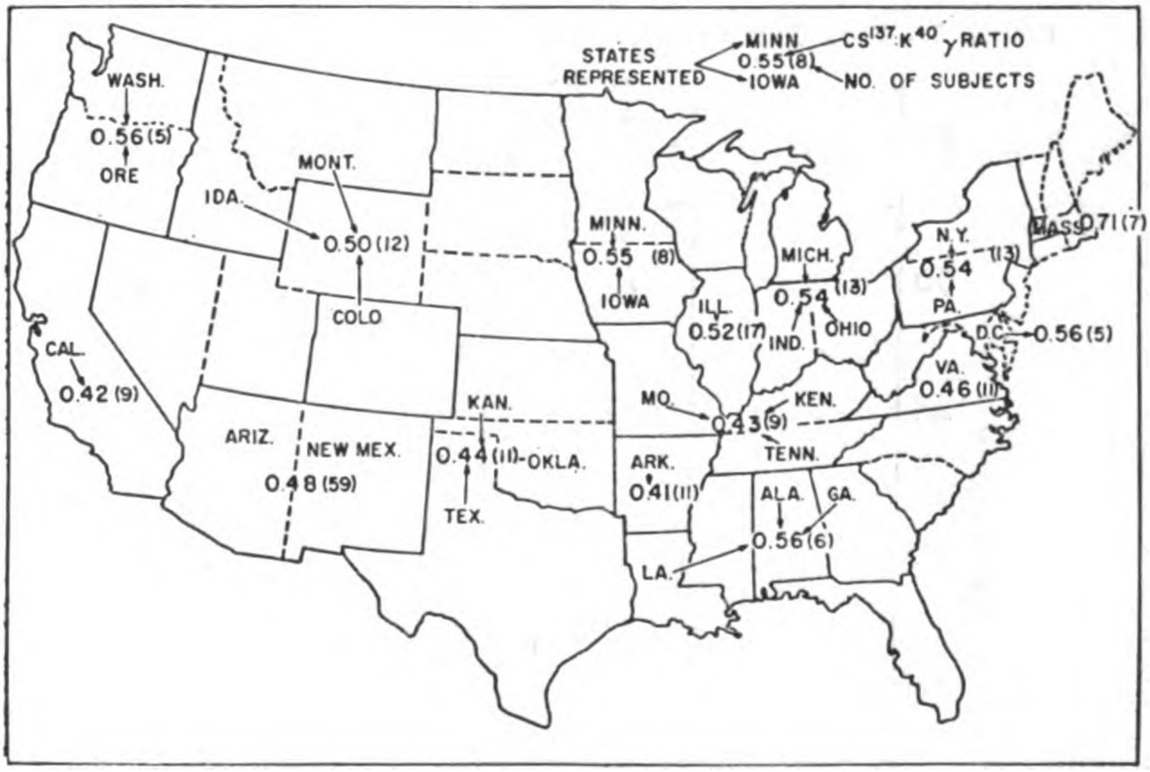


FIGURE 4.—Geographic distribution of cesium/potassium ratios in people.

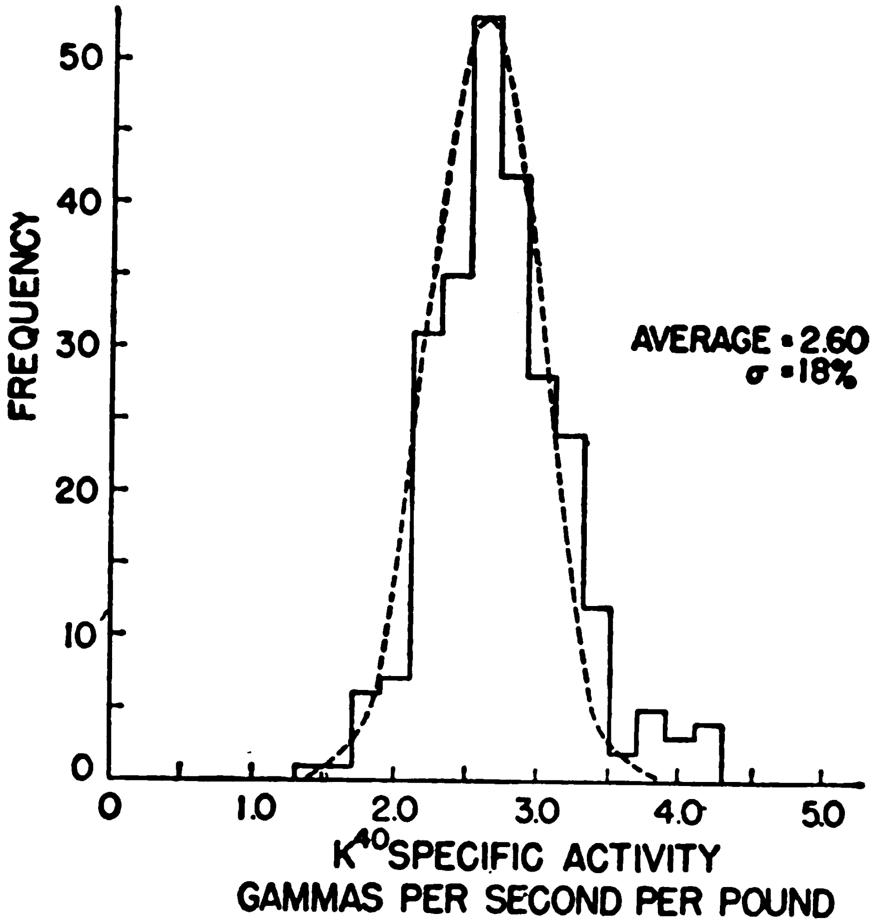


FIGURE 5.—Frequency distribution of potassium 40 specific activity.

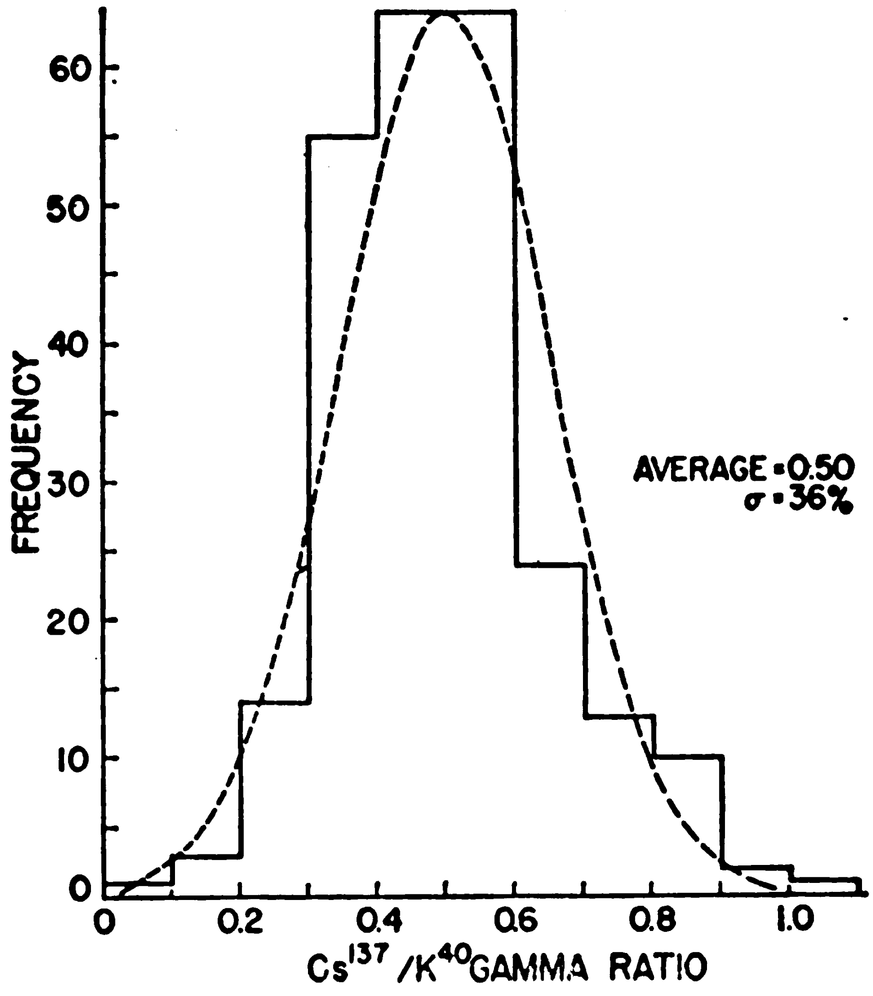


FIGURE 6.—Frequency distribution of cesium/potassium ratio.

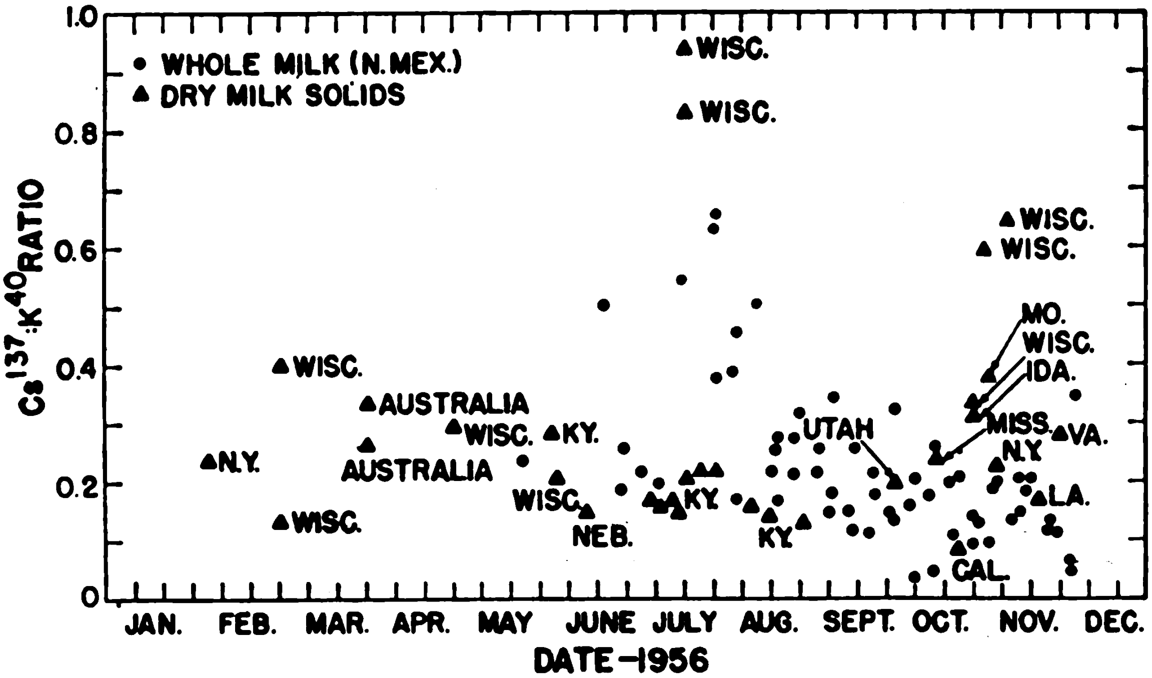
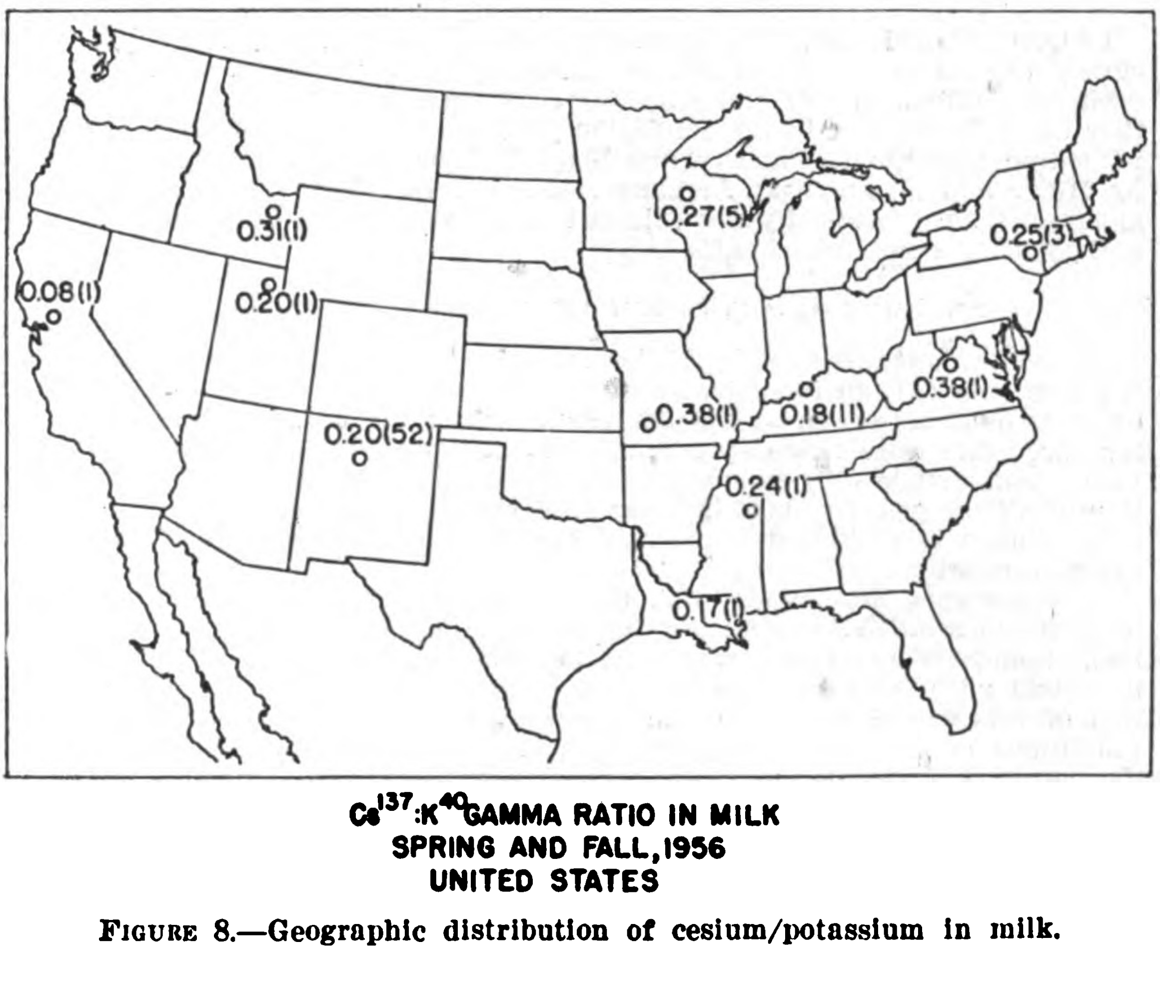


FIGURE 7.—Cesium 137/potassium 40 gamma ratio in milk during 1956.



$Cs^{137}:K^{40}$ GAMMA RATIO IN MILK
SPRING AND FALL, 1956
UNITED STATES

FIGURE 8.—Geographic distribution of cesium/potassium in milk.

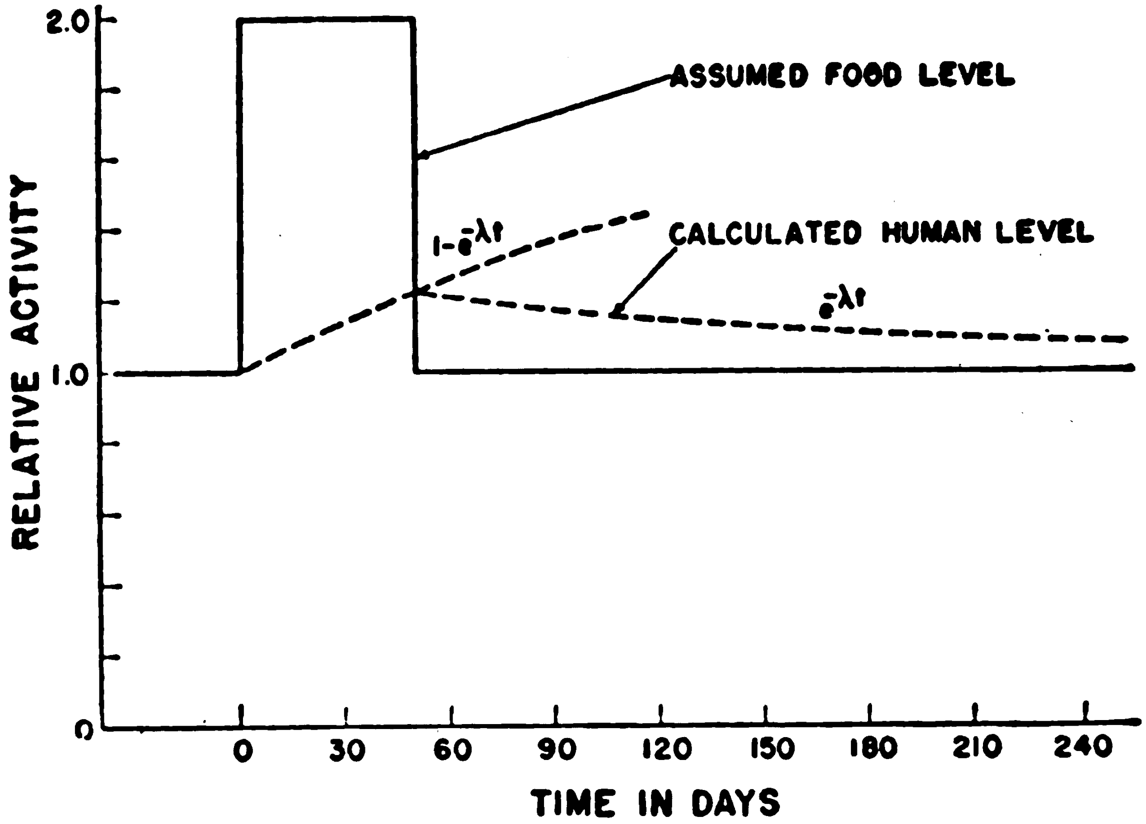


FIGURE 9.—Calculated effect of increased cesium in diet on human level.

Cesium 137 and strontium 90 also are similar in that they are soluble and closely related to potassium and calcium, respectively, which are normal base exchange cations in soil and essential constituents of living matter. In this they differ from other high-yield fission products such as zirconium-niobium 95, ruthenium-rhodium 106, and cerium 144, which have been observed in rug dirt by Miller and Marinelli at Argonne National Laboratory (11) but which are apparently not ecologically concentrated and have not been detected in the general population and in foodstuffs.

POTASSIUM 40 AND CESIUM 137 IN PEOPLE AND FOODSTUFFS

After the announcement by Miller and Marinelli of the presence of cesium 137 in people (6), an intensive program of study of this nuclide in people and in foodstuffs was begun at the Los Alamos Scientific Laboratory. Some 1,500 measurements were made; preliminary results have been reported previously (12). This article (13) summarizes the data collected during 1956. A compilation of all the primary data is being prepared as an unclassified laboratory report which will include detailed analyses of procedures, sources of error, and other information.

Measurements were made with the Los Alamos "human counter" (14), a large liquid scintillation detector that is capable of counting gamma rays from human subjects and from samples of foodstuffs up to several hundred pounds in weight with 100 percent geometrical efficiency. Although the energy resolution of this detector is quite limited compared with that of a sodium iodide (thallium) crystal, it is adequate to permit the simultaneous determination of the cesium 137 (0.661 Mev.) and potassium 40 (1.46 Mev.) gamma rays. Its ultimate sensitivity is 0.0005 microcurie of gramma activity (20 disintegrations per second) for only 100 seconds of counting time. If a 100-kilogram sample is counted, this corresponds to a specific activity of 5 times 10^{-15} curies per gram, which is far below the natural radioactivity of most materials. The natural potassium 40 radioactivity of man (about 0.013 microcurie as gamma rays) can be measured to a precision of better than 5 percent in less than 2 minutes. The cesium 137 determination has a precision of 0.001 microcurie for the same counting time.

Potassium 40 in people.—The average potassium content of the adult male is estimated to be about 133 grams (6, 15, 16) (0.19 percent of gross body

weight of the standard man), which is equivalent to about 400 potassium 40 gamma disintegrations per second.

Figure 1 gives the natural potassium 40 gamma activity of 164 representative subjects, 81 of which were reported earlier (17), plotted against gross body weight. These data show a pronounced scatter of the points to the right of a limiting line and a definite difference between males and females. Correlation of potassium 40 activity with the fat-free body weight of a select group of these subjects indicated the amount of fat to be the principal factor causing variation in apparent potassium content of the body (17). The total body potassium expressed as percentage of gross body weight will show considerable variation, therefore, depending on sex, age, weight, body type and physical activity, but it can be accurately calculated from a determination of total body water.

In figure 2 the specific activity of potassium 40 (gamma disintegrations per second and pound) is plotted against subject age. These data confirm the general decrease of potassium with age reported by Sievert (16). The solid lines indicate the probable upper limits for uncontaminated male and female subjects, respectively. Not enough children have been measured for us to be certain of the trend below age 15. The dashed lines, therefore, are estimates over this region. Deviation from these curves is an indication of possible surface contamination of individuals during periods of local fallout, since only 0.002 microcurie of hard gamma contamination is sufficient to raise the average adult from the lower to the upper limit of the specific activity distribution.

Cesium 137 in people.—Libby (2) adopted the procedure of reporting strontium 90 results as strontium 90/calcium ratios because of the metabolic similarity of strontium and calcium and to facilitate the comparison of different types of materials. Our cesium 137 results are reported as cesium 137/potassium 40 ratios for similar reasons. The principal differences in the biological behavior of the two elements can be accounted for in terms of the appropriate biological half-times. The ratios are reported as the ratio of cesium 137/potassium 40 gamma disintegrations (18).

Figure 3 summarizes the measurements of cesium 137/potassium 40 ratios in people for 1956. The triangles represent results in people from various parts of the United States (the distribution is indicated on the map, fig. 4). Each point is an average for 10 to 20 persons, and the range of values before averaging was 0.1 to 0.9. The circles are averages of measurements on a local control group of 10 laboratory personnel. The scattered high values during the period from June to September are probably the result of surface contamination from tropospheric fallout during Operation Redwing. That they were caused by surface contamination was indicated by their sudden rise and fall, by abnormally high apparent potassium 40 values during the same period, and by the fact that these high apparent potassium 40 values were reduced to normal after bathing in those cases in which remeasurement was possible.

Because of this evidence of external contamination, a line through the more reproducible lower limit of the distribution is regarded as representing the trend of internal activity. The data from the two groups agree in that they indicate a slight rise during the spring followed by a slow decline during the fall. The control group was apparently somewhat lower in the spring, but in the fall the two groups were indistinguishable.

General 1956 averages of cesium 137/potassium 40 ratios for people from various States are presented in figure 4. The results are surprisingly uniform in view of the sizable variations among individuals from the same State. Uncertainty in the averages due to small sample size precludes any deduction of fine structure until more data are available. Within the range 0.5±0.2, the cesium 137/potassium 40 ratio is essentially uniform over the United States, except during periods of tropospheric fallout.

The frequency distribution of potassium 40 and cesium 137 in the population sample is essentially normal. The potassium 40 frequency curve is given in figure 5 as a histogram with a normal error curve fitted to it. The standard deviation of the normal curve is 18 percent. The subsidiary peak outside the normal curve is caused by surface contamination during periods of tropospheric fallout.

Figure 6 shows the corresponding frequency curve of the cesium 137 data for the same population sample. Distribution is again normal, but the width is twice as great as that of potassium 40, the standard deviation being 36 percent. The smaller deviation of the potassium 40 data probably reflects control of the potassium 40 level of the body by a homeostatic mechanism that is not highly de-

pendent on intake. The cesium 137 burden, however, may vary with the dietary habits of the subject and the concentration of cesium 137 in his foodstuffs.

Libby (19) has shown that other trace elements, such as stable strontium, strontium 90 and radium 226, show normal frequency distribution curves with deviations comparable to that observed for cesium 137.

The abnormal subsidiary peak shown in the potassium 40 distribution curve is not present in the cesium data. This indicates merely that the surface contamination distorting the potassium 40 level was present in the cesium 137 channel to a proportional extent and left the cesium/potassium ratio unaffected.

Cesium 137 in milk and other foodstuffs.—Figure 7 summarizes the measurements of cesium 137/potassium 40 ratios in milk during 1956. A peak in cesium 137 activity during July, presumably woing to tropospheric fallout from Operation Redwing, is clearly visible in Wisconsin and New Mexico samples, but is absent from Kentucky milk. This observation is consistent with the path of the cloud as estimated in the United States Public Health Service air sampling network. A peak in the activity in Wisconsin milk in October is indicated also; it may be the result of a foreign test.

Data on geographic distribution of the cesium 137/potassium 40 ratio in milk are as yet scanty, but are summarized in figure 8. As with the measurements of people, one concludes that distribution is essentially uniform within the limits of the data. The uniformity, of course, applies only to the periods in which tropospheric clouds are not present. It is interesting that the two Australian milk samples (fig. 7) are in agreement with the general United States average, lending support to the assumption that the general levels are derived from the stratospheric reservoir. A sample of American dry milk produced in 1942 showed no detectable cesium 137, the cesium 137/potassium 40 ratio being less than 0.02.

Some preliminary measurements of cesium 137 in foodstuffs other than milk are given in table 1. During the spring of 1956, beef and lamb showed a ratio comparable to that of people but considerably higher than similar samples collected in the winter of 1956–57. During both periods, beef and lamb consistently ran higher than pork, which might be expected from the differences in grazing and feeding habits. One sample of dried blood collected in April 1952 showed a ratio less than one-third that of samples collected during the winter of 1956–57.

DISCUSSION

Measurements of present levels of cesium 137 in people indicate that it is of little significance in the potential hazard of radioactive fallout from weapons testing programs. The present average cesium 137/potassium 40 total distintegration ratio is about 0.05. Taking into consideration their respective energies, the radiation dose from present levels of cesium 137 is only one-twentieth of that from natural potassium 40, or about 1 milliroentgen per year. This is about 1 percent of the average total natural radiation dose and less than 10^{-2} of the dose of cesium 137 given in the recommendations of the International Commission for Radiological Protection as the maximum permissible level for the general population (20). Interest in cesium 137, therefore, centers on its potential usefulness in the study of fallout mechanisms.

A rough quantitative comparison of the present average strontium 90 and cesium 137 levels in people is of interest. According to Libby (3), the strontium 90 level in children is about 0.001 microcurie. A fractionation factor of about 10 against strontium between primary fallout and human bone is indicated by the stable strontium data (21) (that is to say, the strontium/calcium ratio in soil is 10 times the strontium/calcium ratio in bone), but cesium can be assumed to be quantitatively absorbed by both cow and man. Although strontium will continue to accumulate because of its long biological half-time, the effective accumulation time for cesium will be limited to some 200 days. If stratospheric fallout is assumed to have begun with Operation Castle (1954), strontium 90 has been accumulating for some 2 years, and this factor will cause it to exceed cesium 137 by $2\times365/200$, or 3.6. Finally, the relative activity yield in the fission process is 1.27 in favor of cesium (assuming fission yields of 0.0510 and 0.0620 for the mass 90 and mass 137 chains and half lives of 27.7 years for strontium 90 and 26.6 years for cesium 137). The overall factor is then $10\times1.27/3.6$, or about 3 for cesium 137, and the estimated level based on a strontium level of 0.001 microcurie is 0.003 microcurie. Considering the crudity of the several approximations, this is in surprisingly good agreement with the observed average of 0.005 microcurie.

TABLE 1.—*Radioactivity in foodstuffs*

Sample	K-40 specific activity (disintegration/sec. lb.)	Cs-137/K-40 ratio	Sample	K-40 specific activity (disintegration/sec. lb.)	Cs-137/K-40 ratio
Meat, spring 1956:			Flour, spring 1956:		
Beef rounds	3.84	0.53	High-altitude wheat (Colorado)	1.30	0.09
Lamb, dressed carcass	3.83	.81	Bleached, enriched (A)	1.70	.32
Pork, fresh hams	3.52	.30	Bleached, enriched (B)	1.49	.27
Pork, loins	3.23	.19	Whole wheat, graham	7.00	.11
Meat, winter 1956-57:			Potatoes, spring 1956:		
Beef, sirloins	2.75	.15	Colorado	7.82	<.06
Lamb, dressed carcass	3.67	.16	Idaho	6.52	<.06
Pork, loins	3.55	.10	Vegetables, spring 1956:		
Pork, loins	3.26	.07	Lettuce	2.34	<.07
Dried blood:			Cabbage	3.20	.12
Illinois, Apr. 1952	9.20	<.07	Carrots	6.82	<.03
California, winter 1956-57	7.30	.25	Fruits, spring 1956:		
Minnesota, winter 1956-57	5.40	.25	Tomatoes	3.81	.03
Texas, winter 1956-57	5.90	.18	Oranges	2.10	.38
			Grapefruit	3.30	.25
			Watermelon	3.75	<.03
			Coffee, spring 1956	30.00	<.06

TABLE 2.—*Calculated cesium 137 intake based on per capita food consumption. Diet was based on Consumption of Food in the United States, supplement for 1954 (22)*

Source	Consumption (lb./mo.)	Cs-137 concentration (mμc./100 lb.)	Cs-137 intake (mμc./mo.)
Dairy products (as dry-milk solids)	5.8	14	0.81
Meats	11.4	3.3	.38
Flour and cereal products	13.0	1.0	.13
Vegetables	16.8	(1)	?
Citrus fruits	3.2	2.4	.21
Potatoes	8.8	(1)	?
Total			1.5

1 Not detected.

Measurements of cesium 137/potassium 40 ratios in milk during 1956 (fig. 7) indicated peak activities resulting from periods of tropospheric fallout. The relative effect of such increases in foodstuffs on the cesium 137 level in people can be estimated from the simple model shown in fig. 9. A step function change in the foodstuff level will be followed by a $(1-e^{-\lambda t})$ change in the population level (where λ is the biological elimination rate), and a new equilibrium value will be reached only after an elapsed time of the order of 1 year. If the foodstuffs return to their previous value before equilibrium is attained, the population level will cease rising and will decay back to its previous value with a halftime corresponding to the biological elimination rate.

This model can be applied to the situation during July and August, when the level of cesium 137 in milk rose by about a factor of 3. Since not enough data are available to define completely the shape of the peak, and since milk values are used as representative of all foodstuffs, the actual peak can be replaced with a step function of the same approximate area. This gives a rise of about 2 times "normal" for a period of 50 days. In this case, the maximum rise in the population level, predicted on the basis of the model in figure 9, is 20 percent. Using the average value of the cesium 137/potassium 40 ratio for the control subjects in the spring of 1956 (fig. 3) of 0.4, their calculated ratio 6 months later is 0.5. The observed summer maximum average was 0.48, in agreement with the model.

An estimate of the biological halftime of cesium 137 in the chronically exposed case was obtained by counting a large urine sample representing 52 man-days of excretion. The sample showed 408 disintegrations per second of potassium 40

(136 grams of potassium) and 40 disintegrations per second of cesium 137. Assuming an average body burden of 0.005 microcurie of cesium 137 for the 6 subjects who contributed urine samples, the excretion rate is 0.004 per day, which corresponds to a halftime of some 180 days if the excretion is exponential and entirely urinary. If fecal excretion is 25 percent of urinary, the halftime would be 145 days. This is in agreement with the biological halftime of 140 days observed on volunteers who ingested 1 microcurie of radiocesium (9).

Using Bureau of Agriculture statistics for food consumption per capita in the United States (22) and our preliminary values for the average cesium 137 content of foodstuffs, the dietary intake of cesium 137 can be estimated (table 2). On the basis of these data, it appears that milk contributes about 50 percent and meat about 25 percent of the cesium 137 found in the body. The excretion rate of cesium 137 can also be estimated from these intake data. This method is only an approximation because of uncertainties in diet and in the average cesium 137 level in the various dietary components. According to the data in table 2, the turnover rate is of the order of 1.5 millimicrocuries per month, compared with the observed value of 0.6 millimicrocurie. Part of the discrepancy may result from using retail weights in computing the diet with no allowance for wastage and loss of minerals in cooking, but the principal source of error is probably the inadequacy of our knowledge about cesium in foodstuffs. For comparison, a similar computation was made for potassium (table 3). The calculated potassium intake is about 3 grams per day, while the observed urinary excretion was 2.6 grams per day. Elkinton and Danowski (23) reported potassium turnover as falling in the range of 2 to 6 grams per day.

TABLE 3.—*Calculated potassium intake based on per capita food consumption*

Source	Consumption (lb./mo.)	Potassium	
		Content (g./lb.)	Intake (g./mo.)
Dairy products	5.8	6.0	35
Meats	11.4	1.2	14
Flour and cereal	13.0	.5	6
Vegetables	16.8	1.0	17
Citrus fruits	3.2	1.0	3
Potatoes	8.8	2.0	18
Total			93

While the spring 1956 average value for the cesium 137/potassium 40 ratio in milk was 0.25, the average in people for the corresponding period was 0.4. This difference may be explained on the basis of the longer holdup time of cesium in the body as compared with potassium. If q_{cesium} is the amount of cesium in the average daily diet, and $q_{potassium}$ is the corresponding amount of potassium, then $q_{cesium}/q_{potassium}$ is the cesium/potassium ratio for the average diet. The milk ratio can be used since it is the most important single factor and is the only one known with any accuracy. The equilibrium amounts of cesium and potassium in the body, on the basis of the simplest model, will be given by the product of $q\tau$ for each element, where τ is the mean life of the element in the body (24). For cesium, τ has been determined to be 200 days; τ for potassium can be estimated from our data on the potassium content of normal urine as about 58 days. Thereforce, cesium should be concentrated relative to potassium by a factor of 200/58, or 3.4. If the average diet ratio is 0.23, the predicted ratio in people is about 0.8. This is too high by a factor of 2.

Libby (4) has estimated stratospheric injection by Operation Redwing at about 6 megatons of fission products in addition to the 18 megatons left from the previous operations. This would imply a 30-percent increase in the fallout rate from the stratospheric (worldwide) component after the tropospheric component is gone. A comparison of the spring and autumn milk averages indicates no detectable increase in the fallout rate. The spring sampling was inadequate; hence there is considerable uncertainty about the proper average. However, it would appear that, if anything, the cesium levels in the fall were lower. This may be a seasonal variation resulting from the change from pasture to hay feeding of the dairy herds, which would conceal possible small increases.

SUMMARY

Measurements of the cesium 137 content of people and of foodstuffs indicate that this nuclide is unlikely to be a decisive factor in the long-term hazards from weapons testing and reactor waste disposal. The amount of cesium 137 now present in the population of the United States averages 0.006 microcurie and shows no marked dependence on geographic location. The average radiation dose received from cesium 137 is one-twentieth of that received from natural radiopotassium and 1 percent of the average total dose from all natural sources. Because of the short biological half-life of cesium of about 140, days, it does not accumulate in the body as does strontium 90. The study of the distribution of cesium 137 is being continued to furnish information on the mechanisms of the fallout process and provide a measure of the rate of fallout and of stratospheric storage.

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13. This work was performed under the auspices of the U. S. Atomic Energy Commission. We are grateful to a number of persons who assisted in various phases of this program. We are particularly indebted to L. D. Marinelli and C. E. Miller of Argonne National Laboratory for helpful discussion and for their generosity in making measurements of interest to us on their crystal counter. Their assistance aided materially in the initial development of this program. J. W. Ballow supplied most of the foodstuff samples, and R. J. Remaley of the American Dry Milk Institute has been very helpful in the procurement of samples of dry milk. H. E. Gilbert of the Los Alamos Scientific Laboratory set up the punched card system used for electronic data processing.
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24. $\tau=1/\lambda=t\frac{1}{2}/0.693$, where τ is the mean or average time the nuclide remains in the body, λ is the elimination rate, and $t\frac{1}{2}$ is the time necessary to remove half the body burden.

STATEMENT SUBMITTED TO THE JOINT COMMITTEE ON ATOMIC ENERGY BY L. D. MARINELLI[1] AND J. E. ROSE,[2] RADIOLOGICAL PHYSICS DIVISION, ARGONNE NATIONAL LABORATORY, LEMONT, ILL.

TOPIC IX. OCCURRENCE OF CS-137 IN THE ATMOSPHERE, BIOSPHERE, AND ITS UPTAKE AND BEHAVIOR IN MAN

The fission product Cs-137 is produced with a yield of about 6 percent and it has a half life of about 27 years. The general characteristics of its distribution and behavior in mammals, as reported by several authors (1-4), indicates only a partial qualitative similarity to potassium. Important from our standpoint is the fact that cesium is excreted by humans at a rate lower than potassium. This leads to a Cs/K ratio in vivo which is from 2 to 3 times the ratio in the ingested food.

Because of its gamma-ray emission, Cs-137 can be measured in the living animal and in bulk material without recourse to lengthy chemical analysis.

To make these measurements, it is necessary to shield both instrument and subject from the radiation emitted by ordinary building materials. This is done by performing the tests in an 8 by 8 by 6 foot room with 8-inch steel walls, weighing 60 tons. This room consists of a bolted frame of angle beams upon which one-quarter inch plates of 12 to 26 inches width are placed in staggered sequence on all sides in order to avoid continuous cracks in the walls. The side plates are held in place by clamping them together between the frame and appropriately placed angle irons.

Gamma-ray radiation emitted by the subject impinges on an 8 inch by 4 inch NaI crystal; the electrons liberated therein produce scintillations which are amplified by a photomultiplier tube and registered, according to their sizes, by a 256-channel analyzer. From the scintillation spectrum it is possible to identify the energy of the gamma radiation (hence the radioelement responsible for it) an dits intensity (hence the amount of material involved). Presently this apparatus has a sensitivity greater than 10^{-9} curies of the gamma emitters under discussion in the intact human subject.

In the summer of 1955, at the Argonne National Laboratory, measurements of the total body gamma-ray activity of members of our staff, visitors from various parts of the country and from overseas, local medical students, etc. (5), disclosed the presence of this radioelement in all of the test subjects. Since then, continual tests on a group of 12 people, has shown an increase in the human burden by a factor of about 2 up to the spring of 1956, and a constant value thereafter, corresponding to about 3.2×10^{-11}C of Cs-137 per gram of potassium (fig. 1). Contrasted to the findings for Sr-90, children do not exhibit high concentration per unit weight.

No correlation between Cs-137 content and geographic origin of the subject was noted (table I). On the other hand, the dependence on the dietary habits of the individual (fig. 2) became evident after a study of the Cs-137 content of food and water. These revealed that bovine meats, milk and milk products constitute the main routes of intake (fig. 3). Subsequent confirmation of these findings on larger representative samples of people and foodstuffs have been obtained at the Los Alamos Scientific Laboratory (6). The observations to date

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[2] Date and place of birth: August 21, 1904, Wilkinsburg, Pa. Education: Carnegie Institute of Technology. Work history: Standard Chemical Co. (radium); Tumor Institute of the Swedish Hospital, Seatle, Wash. (early pioneering work in supervoltage X-ray equipment); National Cancer Institute, Bethesda, Md.; Metallurgical Laboratory, University of Chicago; since 1944 Director of the Radiological Physics Division of Argonne National Laboratory. Member of American Physical Society, Fellow of the American Association for the Advancement of Science, Fellow of the American College of Radiology, honorary Sc. D. (Submitted by witness.)

are consistent with the concepts of (*a*) stratospheric storage, (*b*) constant deposition on grazing lands, (*c*) uptake by cattle, and (*d*) transmittal to man.

Other relatively abundant and long-lived fission products, i. e., Ce–144—Pr–144 (290 day), Zr–45—Nb–95 (63.3 day), and Ru–106—Rh–106 (1 year), easily detectable by our technique in laboratory air, dust, sweepings from house carpets (fig. 4) and soil (7) are not present in the intact mammal in measurable quantities. These findings are consistent with previous observations on their low intestinal absorption following oral intake by laboratory animals (3).

In its present concentration, Cs–137 contributes on the average less than 0.3 mrad to the yearly dose of over 150 mrads which a human being is reported to absorb from natural sources of radiation (fig. 1).

Because of its relatively short life in the cow and of its reputed unavailability to the roots of some plants,[8] the concentration of this radioelement in milk is likely to serve as an excellent indicator of average rate of fallout over milk sheds. Since we can measure directly its presence in the living human we need not rely on theoretical predictions as to the possible individual variations under various conditions. Thus, only a factor of 6 separates the lowest values found in oriental subjects (whose diets are practically devoid of cattle products) to the highest found in the United States of America in an individual on a milk diet.

Pertinent to this discussion and to item X of the agenda are our recent findings on some inhabitants of the Marshall Islands which were measured in our facility by Dr. C. E. Miller. The scintillation spectra are shown in figure 5, and the body contents are included in table I. It should be noted that subject No. 10 is a control living in Majuro Island which did not experience unusual fallout. The next four subjects were inhabitants of Rougelap removed more or less permanently from that island to Majuro Island because of heavy fallout. Their content of Cs–137 is about 2 or 3 times that of the average United States citizen. The reason for this cannot be stated at this time but consumption of coconuts (reputed to acquire Cs) may be implied. The presence of Zn–65 in their body is due to contamination of seafood.

The highest contents of both Cs–137 and Zn–65 were found in subjects Nos. 5 and 18 who were removed temporarily from the island of Uterek because of heavy fallout and returned there after appropriate decay of the external radiation. It is obvious that they represent burdens likely to be acquired by living in zones of relatively high levels of contamination. Yet, despite these circumstances the increased dose rate of radiation to which they are exposed is only a fraction of the normal background of 100 to 160 mrads per year.

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(NOTE.—See middle of p. 745 for a remark concerning this statement.)

TABLE I.—*Gamma ray activity of human beings*

Country	Subject	Date	Cesium 137			Zinc 65		Natural Potassium
			$\mu\mu c$/gK	mμc/man	mrads/yr.	mμc/man	mrads/yr.	mrads/yr.
United States	Average	1956	34.0	4.8	0.29	------	------	Average value for all humans 25-40.
England	T	May 16, 1956	33.0	4.7	.28	------	------	
Do	R	July 13, 1956	35.0	4.9	.29	------	------	
France	J	Sept. 21, 1956	33.0	4.6	.27	------	------	
Denmark	F	Oct. 30, 1956	26.0	3.7	.22	------	------	
Sweden	N	Nov. 29, 1956	32.0	4.5	.27	------	------	
Australia	P	Mar. 27, 1957	50.0	7.0	.42	------	------	
India	Vo	Dec. 18, 1957	18.9	2.6	.16	------	------	
Do	Va	do	20.8	2.9	.17	------	------	
Japan	S	July 26, 1956	24.5	3.4	.20	3.2	0.02	
Indonesia	S	Aug. 10, 1956	13.9	2.0	.12	2.1	.01	
Do	M	do	8.5	1.2	.07	------	------	
Marshall Islands	10	Apr. 5, 1957	65.0	9.1	.55	30.0	.19	
	6	do	69.0	9.7	.58	73.0	.46	
	9	do	73.0	10.0	.61	30.0	.19	
	4	do	79.0	11.0	.67	30.0	.19	
	7	do	95.0	13.0	.80	62.0	.39	
	5	do	1,600.0	230.0	14.0	480.0	3.0	
	8	do	2,700.0	389.0	23.0	230.0	1.5	

Source: NBS Handbook 52—Maximum Permissible Levels: Zn-65=430 μcs; Cs-137=90 μcs.

FIGURE 1

Cs^{137} TRENDS IN HUMANS

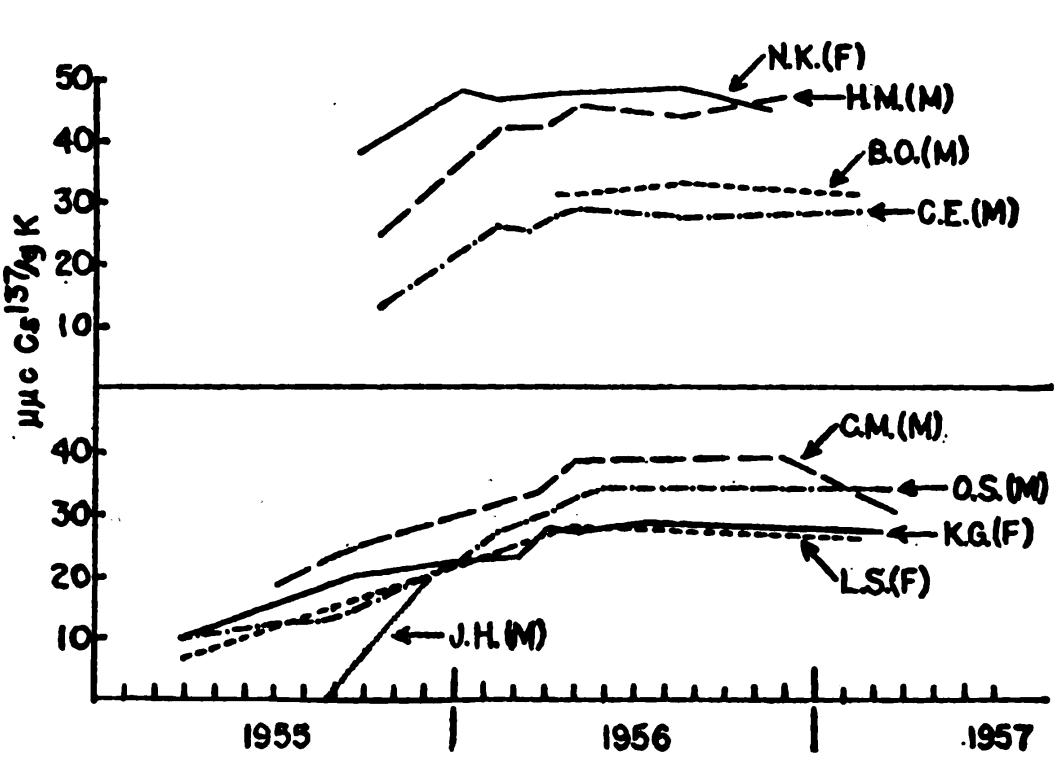


FIGURE 2

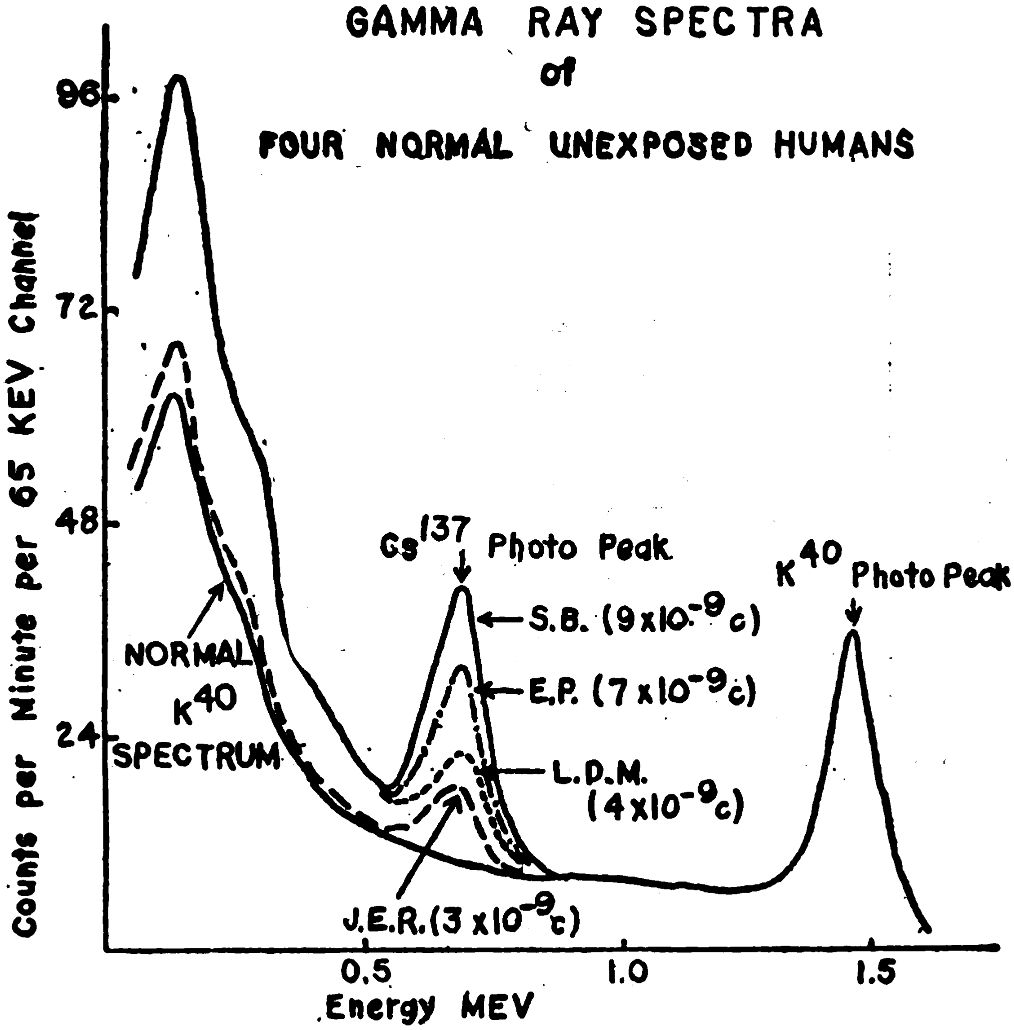


FIGURE 3

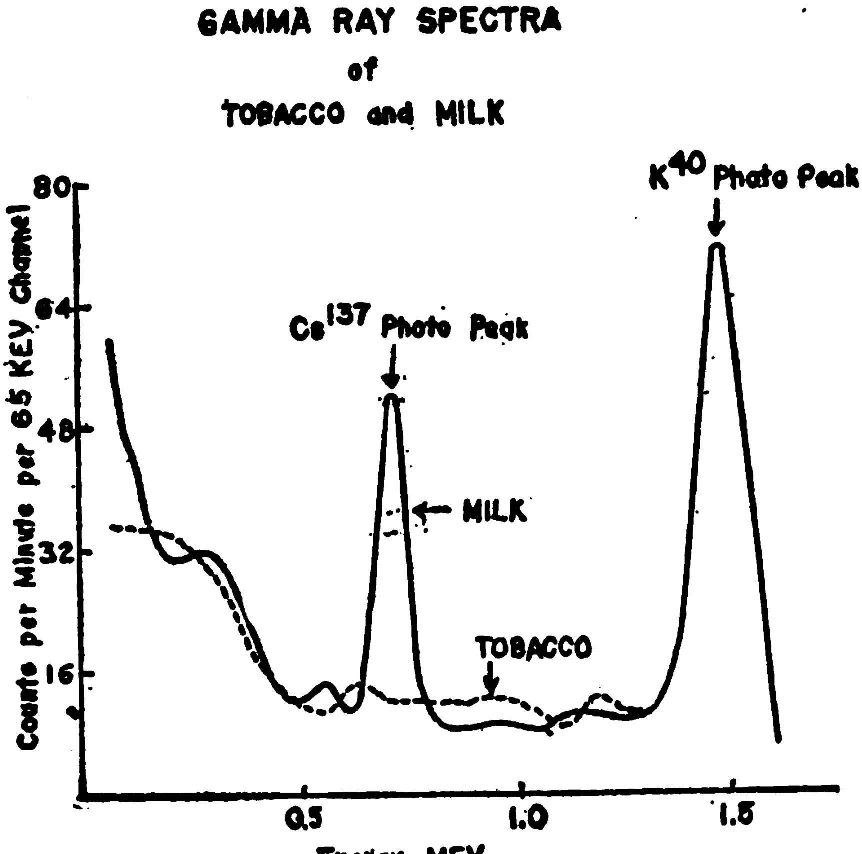
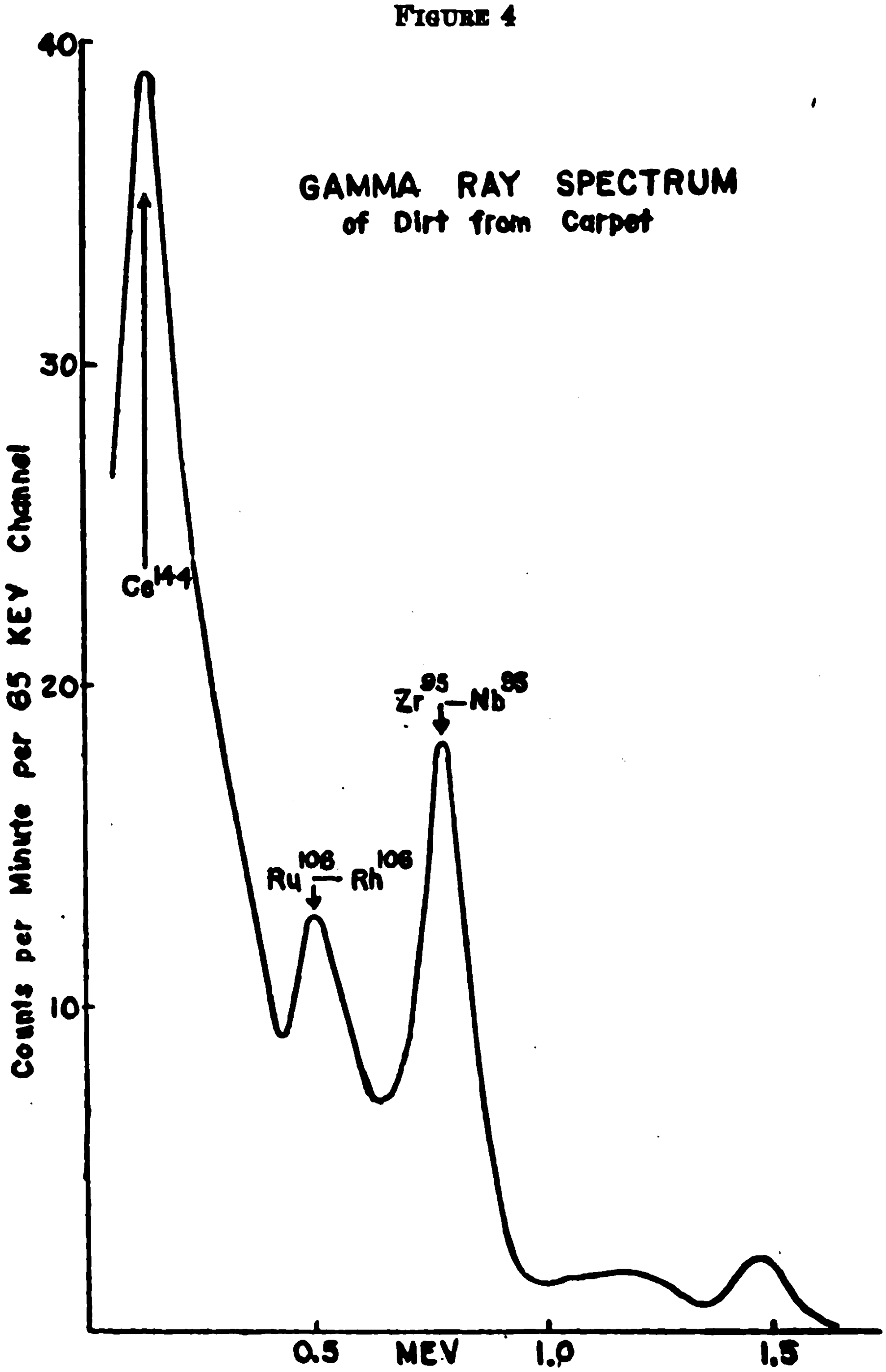


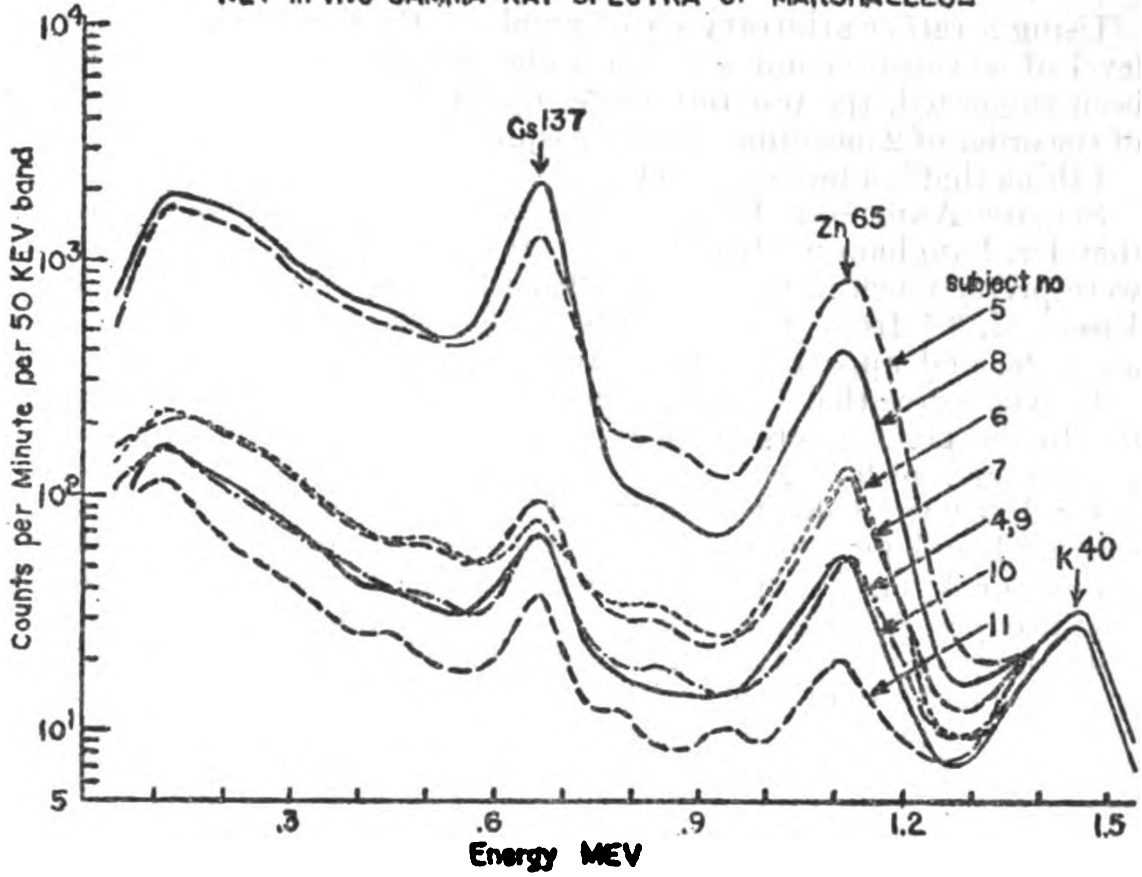
FIGURE 4



GAMMA RAY SPECTRUM
of Dirt from Carpet
Counts per Minute per 65 KEV Channel
40
30
20
10
Ce144
Ru106 — Rh106
Zr95 — Nb95
0.5
MEV
1.0
1.5

FIGURE 5

NET in vivo GAMMA RAY SPECTRA OF MARSHALLESE



Senator ANDERSON. Dr. Kulp, Dr. Eisenbud, and Dr. Neuman, do you and Colonel Hartgering want to get into some questions here, back and forth, that would be helpful to all of us? Dr. Langham, we would like to have you in it also.

Mr. Neuman, do you want to kick off on any comments you may have on the afternoon presentation?

DISCUSSION BY DR. J. L. KULP, MERRIL EISENBUD, DR. WILLIAM F. NEUMAN, DR. WRIGHT LANGHAM, AND COL. JAMES B. HARTGERING

Dr. NEUMAN. I would rather sandbag, if I may.

Mr. RAMEY. It might be desirable if Dr. Neuman could sort of state his case. Some of the members were not here and Dr. Kulp was not here at the time either.

Dr. NEUMAN. As a brief summary, I think it best to say that, in my opinion, the very best evaluation of future levels of bone are those calculated from our equilibrium data on natural strontium because this involves only one assumption; strontium behaves like strontium.

It is also my opinion that the natural strontium data in England and the bulk of the experimental data available in this country indicate that the overall discrimination from ground to bone is about a factor of 8. With this number, one has a fixed relationship between ground level and bone level. If we choose a certain maximum level to be permitted in human bone, we automatically fix a maximum level that can be permitted on the ground. With this number one can calculate the maximum rate at which testing can produce fission

STATEMENT OF DR. H. L. FRIEDELL, SCHOOL OF MEDICINE, WESTERN RESERVE UNIVERSITY[1]

Dr. FRIEDELL. Thank you, sir.

Mr. Chairman, and members of the joint committee, and ladies and gentlemen, I have the unenviable task of trying to introduce an exceedingly difficult and complex subject. We have gathered information on the whole problem of radiation, and the biological effects of radiation, essentially within the past 20 years, and I think it takes a little while before this matures so we can undertstand it fully. Nevertheless, I think there is a place for orientation here for examining some of the basic concepts of what we do know about radiation, about trying to separate various kinds of effects one from the other, when radiation is administered to a biological system. I would like to briefly introduce this.

Time is limited, but I think the others will very readily fill in any hiatuses that exist. There are many none of us can fill in, I think. They will augment wherever necessary the things I talk about.

Representative HOLIFIELD. While we are trying to keep to the schedule, we are not going to cut any witness short. We may ask for documentation, and if you have something that you feel the committee should know, you may proceed to give it.

Dr. FRIEDELL. I think we will want to take a look at how radiation introduces the biological effect, and then we will try to separate some of the things that occur.

It is interesting that radiation we cannot see, hear, feel, or smell, will initiate very profound effects, the way it appears to do this is by this radiation interacting primarily with the atoms that comprise the biological molecules.

The way they interact with the atoms is, in essence, interaction with their electron shells. Most of the physical changes involve these electron orbits, but there are some others which do occur which are essentially insignificant in the broad overall picture.

Specifically, an ionizing particle or powerful photon, a piece of electromagnetic radiation, will come in and pull away an electron out of the atom. Once it has done this, it has now disturbed the atom, made it into an ion, and this ionized atom and the electron will form an ion pair—or it may move the electron into a different energy level. Then it is excited, and may then concern itself with various chemical and biochemical reactions.

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When this occurs it is obvious immediately that the molecule that is then so vital and important to the cell has been disrupted or disturbed and many things can happen to this molecule.

It is of interest to observe that a cell has roughly 10 to the 14th molecules, and a thousand roentgens, a dose which generally is lethal, will affect only about 10 to the seventh molecules. In other words, one ten-millionth of these are affected, and yet this single injury to an atom or molecule among these many will introduce violent and very serious biological effects. The physical effects are over generally in a very short period of time. Immediately thereafter the disrupted molecules become involved in various kinds of chemical and biochemical changes. And again these are over in a few microseconds. So that the process of the physical effects and the biochemical effects are finished within a very, very short period of time, and yet we observe the biological effect in hours, days, months, and possibly even years later. This is an important concept to retain and keep in mind.

Representative HOLIFIELD. This statement is based on experiments with animals?

Dr. FRIEDELL. These are based on experiments primarily in vitro; in other words, studying tissues or systems outside of complex animal, because it would be very difficult to observe it in an animal itself. From the point of view of the occurrence of biological effects, these are observed in animals—correct.

Representative HOLIFIELD. And is applicable to man?

Dr. FRIEDELL. And is applicable to man.

Representative VAN ZANDT. Dr. Friedell, at this point, do you have information concerning the animals that were exposed to radiation in the Mariannas in the 1954 tests?

Dr. FRIEDELL. I am aware of it. I am not entirely familiar with it.

Representative VAN ZANDT. In other words, the Mariannas tests are not involved in your presentation?

Dr. FRIEDELL. I would say what I am going to present would be involved in all biological effects of radiation. These are the basic things that occur at the beginning. They really are the initial things, and I want to proceed much further in developing this.

Once we get the injury at the chemical and biochemical level, obviously the first unit that may be injured is the cell, and all organisms are comprised of cells, as we know, and are complex organizations of cells. We, therefore, can perhaps begin, once we take a look at this matter, to look at the cells themselves and see what kind of biological effects occur here.

Before I go on to the cell, I would like to make this point: Undoubtedly many of you are familiar with the effects of protecting cells with various chemical and biochemical agents. The way this has been done, in effect, is to take a look at some of the biochemical changes that might occur in a system, and see if it would be possible to prevent them or counteract them. Specifically, we might think briefly of a system that can be affected easily and studied readily, and that is the disruption of the water molecules.

Water is an abundant material in biological systems—ordinary biological systems. This water molecule will undergo exactly the same changes that any vital complex molecule might undergo in the cell itself, because the ionization makes no distinction between these. As-

suming roughly the same conditions, it will ionize water just as well as it will ionize anything else. And if you ionize the water, tear it apart, you now produce radicals, so to speak, which will either reunite or will be modified in some other way.

If oxygen is present, which is another very important element, and present in the biological system, they may combine with oxygen to make very powerful oxidizing agents.

It is presumed at levels we talk about, up to several thousand roentgens, that this effect, which is considered an indirect effect (in other words, producing ionization and modifications of the atoms that may not be directly involved in the biological systems, such as water), in turn produces serious effects, because they become noxious radicals, so to speak. They become oxidants, highly powerful oxidizing agents, and may, in the presence of very vital atoms or molecules, alter them and, in turn, produce these serious biological effects.

Therefore, if you were going to attempt biochemical repair of this, or chemical repair of this, you would either prevent the oxidation from producing radicals, or you might introduce something that is an oxygen acceptor, a reducing agent so to speak, and therefore either spare the effect on the molecules or in some way interfere with this occurring.

One of the common compounds we know fairly well is cysteine, which has sulfhydral groups. We do not need to go into the chemistry and exact nature of these things, but they will accept oxygen, and if you introduce enough of these into the cell, these will, in effect, either combine with the noxious radicals to start with, or by the statistical process of dilution prevent some of the vital cell molecules from being affected.

So that this is one attack that has been made in altering or in preventing this biochemical change from occurring and, therefore, being seriously damaging to the cell.

I said earlier that oxygen needed to be present in order for a large number of these oxidizing radicals to be produced, and this is another way in which we can protect the cell. You can reduce the amount of oxygen. You can either limit the amount of oxygen physically by putting the organisms in oxygen-free atmosphere, or by making some physiological change so that the oxygen is low in vital areas of the cell. When you do this you also protect the organism.

So that our beginning knowledge about the biochemical effects are extremely important in giving us an understanding how biological effects will occur, and how we might modify them in the biological system.

Representative HOLIFIELD. Does that have any practical effect on radiation sickness?

Dr. FRIEDELL. Unfortunately, its practical effect is rather small, for this reason: These things must be done immediately before the radiation is delivered, or at the time the radiation is delivered. Unfortunately, if it is done after the radiation is delivered, this, of course, is no longer effective because all of these things we are talking about would have occurred already.

Representative HOLIFIELD. So this is an interesting scientific fact, but from the standpoint of protecting the people from radiation it is inapplicable?

Dr. FRIEDELL. Essentially and practically inapplicable, but it is important in understanding the mechanisms that occur.

I think it would be well to then begin to take a look at what happens in the cell itself, and the people after me are going to talk about this, and extend some of the basic concepts further. But I believe it would be useful to look at the cells and see what we know about them from a radiological point of view.

We have for a long time studied the various responses of cells to radiation, and have made up a little chart which tells us something about how sensitive these are to radiation, and how easily affected they are by radiation. It is important to understand this because, if you are going to understand what happens to the whole organism, you must obviously know how dependent the whole organism is on the economy of any single cell and how easily this is affected by radiation.

I would like to read this to you from the statement that will be introduced in the record. I will read a list of cells I have made up and listed as extremely sensitive, highly sensitive to moderately sensitive, and insensitive.

The basic cells of the hematopoietic system—lymphocytes, erythroblasts, myeloblasts—closely associated, are extremely sensitive to radiation, and small doses will injure these cells severely.

In the same category, I would include the germinal cells of ovary and the germinal cells of testis. As far as our purposes, I would consider these as highly sensitive, and very readily and quickly affected by radiation.

Mr. RAMEY. When you use the word "lymphocyte" what would be the common name for that?

Dr. FRIEDELLL. I would guess that you call these the germinal cells in lymphatic tissues, such as lymph nodes and other tissues that are related to lymph nodes. These also possibly have their origin in the hemotopoietic tissue as well. In other words, the blood-forming organs as well. Perhaps that is what you were referring to.

The next group, which is a little less sensitive—and I would consider these as moderately sensitive to possibly highly sensitive—would be the epithelium of intestinal crypts lining the insides of the intestines, and certain basal layers that originate in the epidermis.

These basal layers of the epidermis and the epithelium of the intestinal crypts, I would say, would be less sensitive, but nevertheless easily affected by radiation.

Now, there are a group of cells which seem to be unaffected except by extremely large doses. I would like to say that all cells can be affected by radiation; if you introduce enough energy, transfer enough energy to the vital systems of the cell, you can destroy them all. But some of the cells require very large doses. Generally the way we look at this is that cells that are highly active and rapidly dividing seem to be affected by radiation more easily than those that are slower growing and more highly differentiated in the sense they are more highly specialized.

These latter seem to be affected by radiation less. I would include in these things like muscles, bone cells proper, liver cells, brain cells, nerve cells, kidney cells. And ordinarily, when lethal doses of radiation are given to the organisms, we will find that these cells are essentially unaffected. You can find no important change in the cells proper.

Now, if you begin to accept this—and it is somewhat difficult to digest without studying it a little bit—you can then begin to understand what happens to organisms as a whole when the organism receives large doses of radiation.

First of all, we can see that certain tissues are going to be promptly injured, and these tissues are going to be the blood-forming cells, such as the leukocytes, and the gastrointestinal cells. Most of the others will be unaffected.

If the organism is vitally dependent on the cells, it will be fatally injured. If it is not vitally dependent upon these cells, there may be modifications, but the organisms proper may not be injured. Therefore, we can begin to understand how we can injure certain cells and yet not affect the organisms seriously.

For example, you can give a fair dose of radiation, which might kill the organisms, to the liver cells alone, and yet the organisms will not die. You can give this kind of radiation to the muscle cells, for example, and the organisms will not die. On the other hand, if you deliver this radiation to the hemotopoietic system, the blood-forming tissue, the organism will die because these blood-forming organs are very vital to the cell.

One of the important things involved is defense against infection. That is, the white cells of the blood-forming organs are very important against infection, and, therefore, reducing the cells would seriously affect the organism and various kinds of infections would rapidly take over.

Representative HOLIFIELD. There is an old saying that a chain is only as strong as its weakest link.

Dr. FRIEDELL. Correct.

Representative HOLIFIELD. When we are talking about the effects of radiation on the human body, and the life span, we must of necessity address our remarks principally to the weakest link in evaluation of the radiation.

Dr. FRIEDELL. Right.

Representative HOLIFIELD. It is of small comfort to know that one section of the body is not so badly affected by radiation, if in the meantime another section of the body which is vital to existence has been destroyed.

I am not saying we should not know this, but I am saying the important thing is to evaluate its effect upon that weakest link in the life cell, the reproductive chain.

Dr. FRIEDELL. This is very true, and when we speak of total body radiation, in other words, when we irradiate the whole organism, then obviously we have to examine the weakest link, and the weakest link would be the hemotopoietic system, and the gastrointestinal tract.

However, when you deal with radio elements, they have certain preferential deposition, so to speak, and therefore, in order to orient yourself, you must understand that certain radio elements that may be administered to an individual will deposit themselves preferentially in one area and, therefore, will essentially have no effect on the gross economy of the individual.

One of the examples I can cite to you is the use of modest doses of radioiodine.

In the adult, the thyroid is a relative insensitive organ, and you can deliver doses to the thyroid in the order of 500 roentgens which

will to all intents and purposes produce no demonstrable effect. On the other hand if you gave 500 roentgens to the total body, or to a very vital structure, you would injury the animal perhaps fatally. This is the reason I introduce this.

Representative HOLIFIELD. By the same token, radio isotopes such as strontium 90, which have been deposited directly into the bone structure and goes right on shooting the powerful rays into the cells around it, would be more damaging than the comparable amount of radiation that was external to the body, would it not?

Dr. FRIEDELL. That is essentially correct. Of course, now we come to one point which is included on our outline—How do we make a decision as to whether certain radio elements are likely to be injurious, and how do we separate radiation coming from radioactive elements or radiation coming from cosmic rays or X-ray machines?

I would like to say this: That all particles or photons (electromagnetic radiation) which are energetic enough to produce ionization will produce the same kind of biological effects, roughly. There are modest differences, but in essence they would produce the same kind of biological effects.

How do we compare radio strontium, for example, with X-rays, or one radio element to another. Let's look at that first.

First of all, the half life of the element is very important. Will it last? Will it radiate a long period of time?—because this is going to determine what the dose is.

Another very important item is how energetic is this particle, and what is the range of this particle. This is tied in with its energy. So we have to know whether it is long lived, what kind of particle it produces, how energetic it is, what is its deposition in the body, will it deposit in vital areas or will it not deposit in vital areas.

These are the kinds of things we have to look at and examine in making any decision about whether a radio element will be serious or not.

Now, strontium 90 happens to fit some of these categories because it is a very long-lived material, and it deposits itself in areas which are vital to the economy of the organism.

Representative HOLIFIELD. Would it be inclined to deposit itself in concentrated areas in the bone, or diffuse through the bone structure?

Dr. FRIEDELL. It appears that strontium 90 is chemically very much like calcium. Therefore, as a good first approximation, we would assume, and I think reasonably conclude, that it distributes itself as calcium does in the bone, which is widely throughout the bone.

Representative HOLIFIELD. But in the case of a broken bone, for instance, that was being repaired, the tendency would be for it to concentrate during the repairing——

Dr. FRIEDELL. During the process of healing, we know there is more calcium deposited at the site of fracture, and, therefore, more strontium 90 would be deposited at the site of fracture.

Representative HOLIFIELD. We hear of bone cancer. Does that take place as a result of bombardment of strontium 90? Does that take place throughout the bone, or is it localized in certain areas of the bone, in the marrow, for instance?

Dr. FRIEDELL. Strontium 90, after you once introduce strontium 90 or, for that matter, almost any element that will seek the bone—and

we have gotten to use the term "bone seeker"—this will distribute itself more or less throughout the bones. Some have special depositions, but it is also the long continued radiation which does the damage. Therefore, it is a question of dose. There is evidence that no matter what radio element you use, if it is a bone seeker, and if it will radiate long enough to give a high enough dose, you will produce bone cancers—at high enough levels. That is what I would like to emphasize.

Senator HICKENLOOPER. Mr. Chairman?

Representative HOLIFIELD. Senator Hickenlooper.

Senator HICKENLOOPER. Doctor, is bone cancer a new thing?

Dr. FRIEDELL. Is it a good thing?

Senator HICKENLOOPER. A new thing.

Dr. FRIEDELL. No, sir.

Senator HICKENLOOPER. Is it something recently discovered?

Dr. FRIEDELL. No, sir.

Senator HICKENLOOPER. Have we not had bone cancer——

Dr. FRIEDELL. Bone cancer has been known almost since time immemorial.

Senator HICKENLOOPER. As long as we have had real medical knowledge?

Dr. FRIEDELL. I think so.

Senator HICKENLOOPER. Bone cancer occurred before we ever had any atomic tests or explosions, did it not?

Dr. FRIEDELL. Yes, it did.

Senator HICKENLOOPER. What would have caused bone cancer many years ago? Is that the absorption of certain nuclear particles, or does it come from some unknown activity of the cells as a starter?

Dr. FRIEDELL. I personally would hesitate to attribute this to the absorption of previous radiation or previous nuclear particles before we began the fallout tests. I think that on the whole this is related to some special biological factor that is yet unknown, and I hope we will hear a little later from one of the other witnesses about some of these special things that might contribute to the production of cancer in general.

Senator HICKENLOOPER. Yes. I mean we have heard a great deal about bone cancer since there has been some radiation released through bomb explosions, but I just wanted to at least assure myself that my belief was right that we had had bone cancer from time immemorial.

Dr. FRIEDELL. Yes, that is true. I will be glad to insert in the record the assertion that bone cancer has been present long before the tests began.

Representative HOLIFIELD. Our concern with strontium 90, though, is that it is an artificial element that is created by thermonuclear explosions and atomic explosions, and it is now a new factor, an additive factor, and experiments have proven that this new element which has been introduced is a cause of bone cancer. That is our concern, is it not?

Dr. FRIEDELL. This is true. But I think there is one very important point we have to look at very hard. That is, what are the levels of radiation? And what evidence do we have that these levels of radiation have produced bone cancer? And what are the bases for

assertions by some that bone cancers will be produced at very low levels in a small percentage of people?

Perhaps later, if I do not forget—I would be glad to be reminded of this—I would offer my humble opinion of this, because I have been looking at this as a radiologist for a number of years, and I am interested in this whole problem.

Representative HOLIFIELD. Why do you not discuss it now? We are on the question now.

Senator BRICKER. May I ask one question before he goes into that?

Representative HOLIFIELD. Yes.

Senator BRICKER. We know that radiation has a tendency to prevent the development of cancer in certain organs?

Dr. FRIEDELL. Yes, sir.

Senator BRICKER. And it is used for that purpose. Would there be any beneficial radiation that might come from strontium 90?

Dr. FRIEDELL. I would say that no radiation is for preventive purposes. I think radiation is used for curative purposes.

Senator BRICKER. For curative, palliative purposes.

Dr. FRIEDELL. Yes, sir.

Senator BRICKER. Would there be any of that effect come from ingested strontium 90?

Dr. FRIEDELL. I could see no benefit that might arise from deposition of radioactive elements.

Senator BRICKER. I have never heard it intimated, but I do know that radiation has been used in the cure of cancer, to help palliate the pain and prevent the growth.

Dr. FRIEDELL. Yes, sir. But in normal tissues I would be opposed, as a matter of fact, to the introduction of radioactive elements as a possible preventive measure.

Senator BRICKER. Of course, we all would. I would not want to take a chance. I wondered if there was any thinking along this line.

Dr. FRIEDELL. No, sir; I do not know of any.

Senator BRICKER. You have not heard it suggested.

Senator HICKENLOOPER. Mr. Chairman, along that line, I would ask one other question, if I may. That is along the line Senator Bricker is discussing.

Could there be any beneficial effect possibly flowing from the introduction of some of these radioactive elements, so far as a cancer that was in the process of formation, or growth within the system which came from other than causes which might have resulted from radiation?

Mr. FRIEDELL. I would say "No."

First of all, the levels of radiation—and again I want to emphasize this: We are talking about entirely different levels. To give you some idea of what the levels are to be curative in the case of cancer (incidentally bone cancer is an extremely resistant form of cancer, and radiation even in large doses is essentially ineffective), the doses that are necessary to cure cancer are in the order of five to ten thousand roentgens. The doses we are talking about, especially from the fallout levels, are in the thousandths of roentgens. So that we are not talking about the same order of magnitude at all.

Senator ANDERSON. I did not follow you on that.

Senator HICKENLOOPER. I think we have done quite a little experimental work in the radioactive iodine in thyroid, and cancer.

Dr. FRIEDELL. Yes, this is true.

Senator HICKENLOOPER. And at least some other attempted specifics along that line.

Dr. FRIEDELL. Yes, sir. In the case of radioiodine, certain cancers of the thyroid are very beneficially affected.

Representative HOLIFIELD. Mr. Van Zandt.

Senator ANDERSON. I want to clear up one thing first.

When you said from five to ten thousand roentgens, then you said the levels we are using here are "thousands" of roentgens?

Dr. FRIEDELL. "Thousandths." Decimal point zero zero one (0.001).

Senator ANDERSON. That is what I wanted. It was not very clear.

Representative HOLIFIELD. Mr. Van Zandt.

Representative VAN ZANDT. Dr. Friedell, in the event of a fracture with the presence of strontium 90, would the strontium 90 in any way slow down the mending of the bone?

Dr. FRIEDELL. I hesitate to answer that, because I have no specific information. But if I may conjecture, I would say it would be slowed down at very high levels of radiation, far above anything we have considered here. And I do not believe you could establish any difference in the growth rate at the kind of levels that are being talked about from fallout.

Representative VAN ZANDT. Then you cannot state whether a low dose of radiation would have any effect on the mending of the bones?

Dr. FRIEDELL. I would hesitate to propose that. I doubt it.

Representative HOLIFIELD. We recognize, Doctor, you are providing us the background statement, and others will go into these different facets.

Dr. FRIEDELL. Very well.

Representative HOLIFIELD. Will you proceed?

Dr. FRIEDELL. With regard to understanding what happens to the whole organism concerning the radiation syndrome, I think we have to look at what happens to the individual from the point of view of the systems that were injured. We try to point out a very cursory relationship between tissue sensitivity, the kind of effects that would produce, cellular effects where the economy of the organs was dependent upon these; and then we can look at some of the systems and pathological findings that might occur.

Since we know the gastrointestinal tract, and the hemotopoietic system are very sensitive to radiation, we can observe, with fairly large doses of radiation, symptoms and pathological effects that are directly related to these. The hematopoietic effect, of course, will appear as a severe drop in the white cells.

I will not go into the kinds of white cells. There are many more competent in this field than I, but this is generally true.

Some of the basic cells in the hematopoietic system are affected, which in turn affects the production of the platelets, which are tissue components in the blood required for the proper function of the clotting mechanism. These are seriously depleted, and under such circumstances you will get all kinds of bleeding tendencies. An individual who is heavily irradiated will show symptoms associated with the gastrointestinal tract, and with the hematopoietic system more or less simultaneously. In the doses that are high, the patient will become nauseated and vomit because of the immediate effects on the gastrointestinal tract, possibly also because some of the vital large

molecules are disrupted, so to speak, by ionization, which we point out can split some of these things up, and it may be these are circulating about and produce some of these effects.

So that an animal that is immediately irradiated in a very few hours may show nausea, vomiting, anorexia, severe diarrhea. This is directly related to what we can observe in the cells themselves, and in the tissue systems. There will be severe hematopoietic changes (the blood changes).

The organism has now lost its defense against infection, and infections will take over very promptly, and we can begin to observe in obvious areas the oropharynx, respiratory, and gastrointestinal tract, ulcerations and infection as a result of this injury to the tissue.

There will be little bleeding points throughout, as a result of interference with platelet formation. If they go on, the animal will be severely injured, and will die, partly as a result of these intercurrent effects, but also because we are unable to replenish some of the vital cells, or the body itself cannot replenish any of the vital cells.

This brings me to a point which we discuss not infrequently——

Representative HOLIFIELD. You are talking of large doses now?

Dr. FRIEDELL. I am talking of large doses in the order of 500 to 1,000 roentgens delivered to the individual.

This brings us to a point of how we might possibly protect the organism against radiation effects.

If we look at some of the very vital cells, it is reasonable to conclude that if it were possible to get these cells to be repopulated, possibly from an outside source, then the animal might be able to recover if the doses have not been really too large.

The recent efforts in this direction have been to get bone marrow cells introduced into the organism that has been heavily irradiated to see whether these cannot repopulate the hematopoietic system, at least until the cells themselves may have had an opportunity to recover.

Representative HOLIFIELD. This would indicate, from a practical standpoint, that you would have to have a bank of bone marrow cells for introduction into the system.

Dr. FRIEDELL. That is correct.

Representative HOLIFIELD. The same as you have to have a blood bank for transfusions?

Dr. FRIEDELL. This introduces many practical problems, and I am not sure it will have any place at all in attacking this problem.

Representative HOLIFIELD. I think it is important to bring this to the point of practical application, because a great many lay readers might think this could be a remedial measure which could be taken in a practical way. Of course, even transfusions would not be of any permanent lasting good if the spleen was affected.

Dr. FRIEDELL. Yes.

Representative HOLIFIELD. Or other blood producing organs.

Dr. FRIEDELL. Right. Essentially, if blood producing organs are seriously affected, it is doubtful if the transfusions have anything other than a transient effect. Generally, in doses of about 500 roentgens, which is presumed to kill, roughly, about half of the humans that may be affected by such a dose, supportive measures might be helpful, such as transfusions, replacing the fluid that is lost as a result of gastrointestinal injury. The use of antibiotics would be very effective be-

cause they would help to combat the infections occurring while the defenses were down.

Representative HOLIFIELD. From a remedial standpoint, this would be more valuable to those who had not received a lethal dose. To people, say, who received 100 or 200 roentgens, these measures would be of some value?

Dr. FRIEDELL. These measures may be valuable even at high doses, because it is possible—if 50 percent survive, say at 500 roentgens, it might be possible to push that up a little further, 60 or 70 percent. This is conjecture. We do not know. This is very important. When we get too high doses, over 1,500 roentgens, it seems that no measures are effective and we are unable to use any of these in any useful way.

Representative HOLIFIELD. Of course, from a practical standpoint, in an exposure of our people, it would be completely beyond the resources of the medical world to give this remedial treatment, would it not?

Dr. FRIEDELL. I think this could be true. But, if we are examining the whole problem, I think we would be overwhelmed by other things that would occur at the same time, and this would be essentially a small problem. There would be many, many more severe and difficult problems.

I have devoted my remarks primarily to the acute effects up to the present time, and we have talked about how we can assess these changes in the whole organism more or less immediately, and in fairly large doses.

It is well also to consider what would happen if the doses are lower, and if the animal survives. Is the animal completely unscathed if radiation has been delivered in smaller doses when comparatively few, or perhaps none have been killed?

Here I think we get into the problems that are very difficult to answer, and very difficult to prove effectively at the present time. This is an area where a great deal of study and research is required.

I would like to divide these, roughly, into three areas:

1. What is the effect on the vitality of the organism?
2. What is the effect on the production of malignant tumors?
3. What is the possible effect on future generations, the genetic effect?

The last I will speak very briefly upon, because many better speakers than I am will discuss it further. But I would like to say something about these points.

First of all, there is evidence indicated in animals with high doses—and by "high doses" I mean accumulation of many hundreds and even thousands of roentgens—that you can produce leukemia in susceptible strains.

I would like to point out that to produce leukemia a susceptible strain of mice must be used—that is, these mice must be such that they are genetically able to produce leukemia spontaneously. If the mice are not a susceptible strain—that is are not leukemia bearing—then the production of leukemia in such a strain is extremely difficult if not impossible. Thus one element that is essential is that the animal must have had inherent tendency to produce leukemia in the first place.

Secondly, tumors have been amply produced in animals with large doses of radiation, and tumors of all kinds. Whether it is strontium

90, phosphorus 32, or total body radiation, or radium, wherever you produce large doses and selective deposition in sensitive areas, you can produce tumors of all sorts. This is unquestioned.

Senator HICKENLOOPER. Benign, or other kinds of tumors?

Dr. FRIEDELL. Let us for the moment consider only the malignant tumors, tumors that will destroy the animal and fit all the criteria that people insist upon being characteristic of malignant, that is, they will spread to other tissues, and generally have the appearance of cancer. I think here is where we get into a problem.

If it is clear that there is evidence that tumors can be produced, and leukemia can be produced in various kinds of organisms under various conditions, it would be well to see if we could quantitate this. In other words, are there twice as many tumors produced when the dose is twice as high?

In general, this appears to be not well controlled, but there appear to be more tumors produced when the doses are higher. Under these circumstances, you can set yourselves up a little model or framework in which you show that the dose is related to the production of tumors, and the number of tumors.

Senator ANDERSON. Can I ask you there what you mean by "when the dose is high"? Can you give us the level again?

Dr. FRIEDELL. Yes. Generally, when we think of high doses, we think of doses in the lethal range, and perhaps I have been a little bit loose in this regard.

If you take animals that have been exposed to a lethal dose, 50 percent dose, that is, a dose in which 50 percent of the animals will succumb, and keep the survivors, the amount of radiation will be very high.

Senator ANDERSON. What I am trying to get to is this: We were talking previously about 5,000 to 10,000 roentgens.

Dr. FRIEDELL. Yes, sir.

Senator ANDERSON. Whereas, from fallout we are talking in thousandths, tiny fractions.

Dr. FRIEDELL. Yes, sir.

Senator ANDERSON. Now the things you are discussing, are they connected with fallout from nuclear weapons in any way, or an accumulation?

Dr. FRIEDELL. It is what we may be discussing, sir, and I would like to amplify this a little bit to show how this concept is approached. I will talk about those very low levels in just a moment.

Senator ANDERSON. All right.

Dr. FRIEDELL. In effect, what I am saying is large doses produce tumors and leukemia, and by "large doses," I am talking about thousands of roentgens, many hundreds of roentgens.

If you set yourself up a model in which you show that these doses will produce tumors and leukemia, and then extrapolate down to low levels, especially on the basis of how the data looked at high levels, you can begin to conjecture that perhaps these lower levels could in a very small percentage of patients or individuals produce these kinds of tumors.

Now, I think what we need to look at, and what this group is going to look at in the next couple of days, is how good are these extrapolations—Is this conjecture? Is this soundly conceived?

I wish I could offer an authoritative statement right now to end all of this discussion, but unfortunately I cannot. However, I would like to say this: That I am concerned about the fact that there are no data at the very low levels. It is just nonexistent. Much below a hundred roentgens, or 25 roentgens in the case of mutations, we have no data.

Representative HOLIFIELD. You are speaking of man?

Dr. FRIEDELL. In animals as well. I am speaking of all complex biological systems.

Representative HOLIFIELD. Have not you been able through following mice, for instance, through several generations, to establish any data of this type?

Dr. FRIEDELL. Yes, but these have been in large doses. These have not been in hundredths, or tenths of roentgens, they have been in doses far larger.

One of the reasons we are using large doses is that you have to have some kind of statistical security in looking at the information. To discover an effect which would occur once in 10,000 times, you would require an inordinate number of biological specimens, and so on.

But I would like to point out that this difficulty exists, and for this reason we do not have really secure data.

Now the people who propose that the doses at very low levels can produce effects have pointed out the data at higher doses are such that permit them to make these extrapolations, and there are many ways of looking at this. You can do it mathematically, you can do it by examing the mechanism by which these effects are produced, and in this way kind of develop some hypotheses which will permit you to make some conclusions.

I feel that the data at the very low levels are based on this kind of hypothesizing, and therefore, correctly are not available at the present time, and perhaps will not be available for a long, long time because of the difficulty.

We should, therefore, be slow in accepting these if we need to use it for a vital decision.

I think at the present time these data are not good enough to make very extreme or vital decisions in this regard. I think all of us should look at this to see what is the truth of the matter and what scientific evidence we can find which will permit us to make these conclusions.

Senator ANDERSON. May I try to translate that to myself and see if I got it correctly?

Dr. FRIEDELL. Yes, sir.

Senator ANDERSON. Do you tell us the data are not now good enough for the Congress, for example, to reach a decision on whether continuation of tests at the present level is wise or unwise?

Dr. FRIEDELL. I would say that, sir. I do not believe the data at the present time are good enough to make conclusive decisions.

Senator ANDERSON. If it is not good enough for the Congress, it is not good enough for the Atomic Energy Commission, either, then, is it?

Dr. FRIEDELL. Let me revise that statement.

Senator ANDERSON. That is the trouble. If it is not good enough for the Congress to reach a decision, it does seem to be good enough for the Atomic Energy Commission to reach a decision. They can sit in their ivory tower and say, "This is all right," but to get back to

the Congress which is having to deal with human beings, the data are not good enough.

Dr. FRIEDELL. I would say the data are not such as to suggest any vital or important decisions which would alter the course being pursued at this time.

First of all, they are not good enough to be conclusive, and there are other reasons I will go into further, which would make me have reservations on what they mean in general.

One of these is, when talking about these doses we are talking about the levels which fit into the dose levels we are receiving right now. If you are interested in numbers, each one of us are receiving or having about 3,000 to 5,000 ionizing events per cubic centimeter per second. Now it is 10,000, now it is 15,000, something of that order. So there are a lot of ionizing events going on now. We are living in a sea of radiation rising from various things, and this will be discussed, I am sure, or has already been discussed.

Senator ANDERSON. I think that is a very useful statement, and I appreciate it. I am only trying to say, if it is difficult for the Congress to get any satisfactory or conclusive answer from the existing data, that it must be equally disturbing, I would think, to the Atomic Energy Commission if they want to take a fair look at it. That is my only point.

Dr. FRIEDELL. I would think—if I were going to conjecture again, on how they are looking at it. I think they are disturbed by this, and I think their examination of the data would suggest to them there is no reason to stop these tests because of the levels of radiation. The levels are apparently at levels which are far below levels which we have established as being the acceptable doses, and are quite within the range of radiation occurring at the present time all around.

Senator BRICKER. Mr. Chairman?

Representative HOLIFIELD. Senator Bricker.

Senator BRICKER. Is there any thinking along the line that, if there were no background ionizing radiation at all, the human body would be devoid of cancer?

Dr. FRIEDELL. I do not have any opinion about this, sir. But again I will conjecture that I think the cause for malignant disease lies in some biological derangement that is really not related——

Senator BRICKER. To radiation?

Dr. FRIEDELL. Alone.

Senator BRICKER. But ionization of the cells?

Dr. FRIEDELL. Right.

Representative HOLIFIELD. You used the word "alone"; it is not related alone to that point. You think there may be other causes? I was afraid that word was missed by the audience. I think it is important.

Dr. FRIEDELL. I think at the proper levels, high enough levels, these effects can be produced. At the very low levels where the levels begin to approach the natural levels we are facing, I think there is grave uncertainty. This, of course, is concerned with the whole concept of whether the effects will be occurring at low levels in the same rate that they are occurring at high levels, and whether there is such a thing as threshhold. In other words, is there some level below which nothing will happen?

Again, this is very difficult to establish. The evidence, as I see it, is inconclusive in this direction, and if I had to choose, if I had to make a decision now, if I were compelled to make a decision, I would hesitate to accept this concept that a threshhold does not exist.

Senator BRICKER. That is the reason I asked the question, frankly. It is your thinking, then, that there is a biological cause of these abnormal growths in the human body?

Dr. FRIEDELL. I do, sir.

Senator BRICKER. Above and beyond and separate from the radiation?

Dr. FRIEDELL. Yes; I do.

Representative HOLIFIELD. Will you state your observation in an affirmative way rather than a negative way? And then tell me if you apply that equally to somatic as well as reproductive cells.

Dr. FRIEDELL. I sort of left out the reproductive aspect of this.

Representative HOLIFIELD. That is just what I thought maybe you left out. That is why I wanted you to restate it.

Dr. FRIEDELL. I would say, from the point of view of production of tumors, and leukemias, I would hesitate to accept the concept that a threshold does not exist. From a point of view of genetics—now I am in a field where I am even less familiar—I think the data are not unassailable, but I think they are stronger than they are in the concept of cancers or leukemias.

Again I would like to point out the data on mutations and genetic effects do not exist below 25 roentgens.

The basis for making these decisions is careful study of the data, by protracting the radiation, by fractionating it, by observing the effect of dose, and this gives them a line which can be extrapolated down below. I have no objection to these extrapolations, and ever since Descartes introduced the coordinate system, this is a privilege of all. I do not really understand whether these things necessarily follow this rule. I would think I would want a much better and much more carefully controlled examination of the effect at very low levels.

Representative VAN ZANDT. Mr. Chairman?

Representative HOLIFIELD. Mr. Van Zandt.

Representative VAN ZANDT. Dr. Friedell, to be conclusive, would you go into a little more detail as to what must be required?

Dr. FRIEDELL. What must be required?

Representative VAN ZANDT. Yes.

Dr. FRIEDELL. As far as our studies go?

Representative VAN ZANDT. Yes.

Dr. FRIEDELL. I think probably the most important thing is to look at the basic aspects of what occurs in biological systems, so that we can understand the mechanism, so that we can see whether once we understand this mechanism it fits in with the data which we already have. And here I feel is where the greatest possibility for really learning something about it exists. I would like to see this emphasized over and above the efforts to perhaps use 10 million mice at very low levels. I would think that basic studies of biochemical effects, the possible way in which these things occur, would contribute more than doing such statistical studies——

Representative VAN ZANDT. Would you apply a time factor?

Dr. FRIEDELL. I would hesitate to apply a time factor, but since I am making all sorts of conjectures, I will add one here.

I will say that perhaps in 5 to 10 years we would have a much better understanding of this.

Representative HOLIFIELD. Of course, if your understanding at that time had to be revised downward as the chart this morning has been revised downward, we would be dealing then with an accumulation of substance which would be ineradicable, and we would have it; would we not?

Dr. FRIEDELL. Yes.

On the last page of my little statement, I tried to put these things together. I think two problems exist.

First of all, I think there is a problem of examining the data scientifically to know where the truth lies.

Assuming the correct consequences of this, assuming no threshold, and all radiation is injurious and produces some effect, I think we have to fairly assess this kind of hazard compared with the hazard which now exists. I do not feel we have yet really looked at this in an unbiased and nonemotional manner. I think it can be done, especially if we look at it over a long period of time so we do not rush into any important decisions at this time.

Senator BRICKER. You have discussed the control of abnormal growths, the cause of them, the somatic effects in a limited way. What have you to say about the length of life?

Dr. FRIEDELL. Here again I do not have any good, well-founded opinion. The data that are available indicate that for large doses in animals, there is a decreasing survival due to all the causes that would occur ordinarily in these animals. In other words, they die of various things, only these various causes of death appear a little earlier in heavily irradiated animals.

Again the same problem exists. Can you extrapolate down below?

This figure we heard earlier that somebody will have suffered a loss of 20 days in survival. It seems to me there can be no data at this level, because this would require an inordinate amount of animals at very low levels to establish this, and I just do not have that kind of sureness about studies in which you observe one event in hundreds of thousands of others.

From the point of view of the span of life, I feel for projections to low levels this falls in exactly the same kind of category. We cannot determine what is happening at very low levels.

I think I can understand the reasons and conjectures and hypotheses of people who propose that this occurs, but they make me uneasy, and I am loath and not ready to fully accept them. I think they are not incontrovertible.

From the point of data on humans, there is some published evidence to show a radiologist may, by the nature of his activities, have received more radiation than others. I am a radiologist myself. I turned some data recently published over to the statistician, and he wrote me a letter saying that these data were suggestive, but by no means conclusive. And the way in which you sample the various groups makes a tremendous amount of difference, and even though averages of the compared group, for example, might be the same, the distribu-

tion could make a tremendous difference. I know this has been touched upon by others who feel the same way.

Representative HOLIFIELD. We found that averages are a little bit unreliable to rely on in some instances.

Dr. FRIEDELL. Yes.

Representative HOLIFIELD. Thank you very much. Are you planning to stay the rest of the day? We might have you on in the discussion late this afternoon.

Dr. FRIEDELL. Yes, sir.

Representative HOLIFIELD. Thank you, sir. Your prepared statement will be placed in the record at this point.

(The prepared statement referred to follows:)

MATERIAL PRESENTED BEFORE THE JOINT COMMITTEE ON ATOMIC ENERGY BY H. L. FRIEDELL, M. D.

The biological effects that are observed when tissues are irradiated must begin as a result of the physical interaction of ionizing radiation and the atoms that comprise the biological specimen.

This interaction appears primarily as ionization—that is, ejection of an electron from the orbit by excitation, in which the energy level of the electron without ejection probably also plays a part.

The excited and ionized atoms and molecules then appear to interact in various ways, eventually producing profound chemical and biochemical change. The immediate physical and chemical changes are probably over in fractions of a microsecond, or at most a few microseconds. The biological effects may not appear for hours, days, or months.

One interesting aspect of this energy absorption is that only a small absorption of energy produces such widespread biological effects. One thousand roentgens, a lethal dose, involves only a very small fraction of a calory per gram (2×10^{-8} calories per gram). Another way to look at this is that the energy which is absorbed appears to affect directly only about 10^{7} molecules in a cell which generally contains 10^{14} molecules.

In outline form, we need to think of the chain of events as (1) physical interaction, (2) chemical and biochemical changes, (3) cellular changes, (4) going on to tissue and organ system alteration, and, finally (5) injury to the whole organism.

The chemical and biochemical effects which occur are at the present time somewhat obscure and receiving much study. One of these effects that has been of interest and which appears to be tied up with some of the observable biological changes are the indirect effects resulting from the disruption of the water molecule abundantly present in living tissue. In the presence of oxygen, this results in producing highly active water radicals which in turn attack vital molecules in the cell since they are very active oxidants.

It has been found that, by depriving the cell of oxygen during the radiation period, these effects can be markedly minimized. By introducing chemicals which are in themselves oxygen acceptors, the oxidation effect on sensitive tissue systems may be spared and the radiation injury is markedly minimized.

At the present time, the best working concept is that the indirect effects are very important at the levels of radiation with which we are concerned (500 to 1,000 r.), that efforts to correct or prevent the chemical and biochemical disturbances as a result of disruption of the water molecules protects biological systems in an effective manner. It should be pointed out that this must be done during the radiation and is completely ineffective after the radiation has been delivered.

The cellular effects have been quite thoroughly studied. On the whole, the nucleus is known to be more sensitive than the cytoplasm. Cells appear to be affected primarily with respect to their function of division and recent studies have, therefore, been directed at this aspect. From the biochemical point of view, the nucleic acid metabolism, and particularly DNA in the nucleus, has received considerable attention.

From a general point of view, it is best to look at the cellular changes and try to understand the difference between cells and their place in the economy

of the whole organism. At one end we have extremely sensitive cells. These may be listed as follows:

(a) Extremely sensitive: Lymphocytes, erythroblasts, germinal epithelium of testis, myeloblasts, germinal cells of ovary.

(b) Highly sensitive to moderately sensitive: Epithelium of intestinal crypts, basal layers of the skin.

(c) Insensitive: Connective tissue, bone, liver, pancreas, kidney, nerve, brain, muscle.

An estimate of the variation in sensitivity permits us to understand better the effects on tissue and on the whole organism. The effect on the whole organism is obviously determined by how dependent the organism is upon extremely radiosensitive tissues. Since the hematopoietic system is one of the extremely important tissues upon which the organism vitally depends, it can be explained that irradiated animals can be readily injured by comparatively modest doses. The animals suffer infections and will die a hematopoietic death if some measure for correction is not instituted. The epithelium of the gastrointestinal tract is less sensitive but nevertheless readily affected by large doses of radiation. At the lower dose levels there is rapid recovery. At the higher dose levels recovery is markedly impaired and the animal may succumb to what is known as a gastrointestinal death, sometimes even before the hematopoietic changes can manifest themselves.

Many tissues are quite unaffected by radiation at levels which would cause death of the whole organism. Therefore, under certain circumstances, particularly when certain radio elements are used, considerable radiation may be delivered without seriously affecting the organism as a whole since the radiation is confined to a comparatively insensitive structure. Also, radiation delivered to sensitive tissues which may not be vital to the organism proper will have comparatively little effect on the individual. As an example, radiation delivered to the thyroid, which in older individuals is comparatively insensitive to radiation, will not produce any appreciable effect on the whole organism. Also, radiation delivered in modest doses to the gonads may produce sterility but will otherwise appear to have no demonstrable effect on the individual proper.

It would be well to point out that the manner in which radiation is delivered is highly important in considering the possible biological effects (excepting genetic changes which will be discussed briefly later). Protraction and fractionation of the radiation markedly reduces the total somatic biological effect. Radiation delivered to specific parts of the body markedly alters the response so that shielding of part of the body increases the dose necessary for lethal effects.

Generally, radiation delivered over a long period of time gives some of the tissues an opportunity to recover (a process which is poorly understood) and, therefore, increases survival.

Specifically, it is well to point out that species sensitivity varies among mammals. Following is a list which gives some concept of the range that may exist:

LD_{50} dose:	*Roentgens*	LD_{50} dose:	*Roentgens*
Guinea pigs	200	Rats	700
Pigs	300	Hamsters	750
Dogs	350	Rabbits	800
Mice	450	Bacteria	100,000
Monkeys	500	Viruses	1,000,000

Man is estimated to fall somewhere halfway through this range of mammals and the LD_{50} dose (that is, the dose necessary to kill 50 percent of the individuals) is presumed to be about 500 roentgens.

As a result of whole-body radiation, certain specific tissues effects are produced. These in turn determine the clinical syndrome. Briefly, the effects which first appear are nausea and vomiting, which can be explained on the injury to the gastrointestinal tract. Prostration, diarrhea, and anorexia may promptly occur with larger doses—again the result of interference with gastroitestinal function and dehydration. The blood forming tissues are simultaneously affected, but evidence of their severe depression is slightly delayed. There is marked depletion of the white cells—later the red cells. The elements involved in clotting are seriously affected and hemorrhages as a result of this derangement soon appear. The individual is susceptible to infection for two reasons—one, depletion of the white cells, and secondly, by impairment of the ability to form antibodies. As a result of this susceptibility to infection, the

oropharynx, respiratory and gastrointestinal tract are prone to ulceration and infection. The central nervous system is essentially not affected.

The neuromuscular system and the specific function of the liver and kidney appear not affected at lethal doses, fitting in with our general concept of radiation sensitivity of tissues. Epilation occurs as the dose approaches the LD_{50} range, since the basal cells of the skin and their derivatives are quite sensitive.

Of concern also are effects which do not appear immediately as the result of radiation but are either postponed until late in the life cycle of the organism or may be observed only by special methods of testing. One of these is the question of general impairment of viability of the organism which may be susceptible of determination by observation on longevity.

In animals at fairly large doses there is good evidence that animals do not survive as long as nonirradiated controls. Whether this may be extrapolated to low dose levels is uncertain and is by no means conclusively established. There are no good data at levels of less than 100 roentgens and those that are available do not indicate any change in longevity. Recently, there has been presented evidence that radiologists who, having received more radiation than others by the nature of their activities, have suffered a reduction in their life span. Although the data are suggestive, statisticians have seriously questioned the significance of these data because of the method of sampling and of the uncertain relationship of the age groups.

Another late consequence of radiation in which the animal survives is the production of malignant new growths (tumors of various kinds) and leukemia. In animals, large doses unquestionably produce an increase in the incidence of cancers and leukemias. It should be pointed out that it is necessary to use a susceptible strain and that in certain insensitive strains it is not possible to produce these changes. The question as to whether this occurs in man, I think, has been amply demonstrated.

I believe there is evidence to show that when humans are heavily irradiated, tumors and lukemia will appear. The question is whether this occurrence may be satisfactorily quantitated and attributed to low levels of radiation. We have no data in this respect. Theoretically, considerations suggest that this may occur, but at present are entirely in the realm of hypothesis and must be considered inconclusive.

A third important late effect is concerned with the injury to the genetic tissue of the organism, and here I believe we should now make a distinction between sterility and genetic alteration.

The cells of the gonads which develop into sperm and ova and concerned with reproduction are extremely sensitive—comparable to that of hematopoietic tissue, and are injured with modest doses of radiation. From the point of view of sterility, it requires about 300 to 400 *r* to induce sterility in the female and perhaps 500 *r* to induce sterility in the male—that is, there is essentially complete loss of viability of the reproductive cells so that no progeny is possible.

This must also be distinguished from injury to the cells in the reproductive organs having to do with sexual characteristics—that is, male and female characteristics and other hormonal influences. These cells are not readily injured by radiation and are comparatively insensitive. Although it is easy to produce sterility, it is very difficult to eliminate the normal sexual characteristics—that is, male and female characteristics and other related functions.

The important change which has significance for all of society concerns itself with the alteration of the genes proper. Without going into the concepts of physical characteristics of the gene and its position in the reproductive apparatus, it is sufficient to say that these alterations are known as mutations which are essentially uninvolved in the reproductive capacity of the individual but produce its effects in subsequent generations.

Briefly, these mutations as a result of radiation appear to be similar to mutations produced by other causes. (Radiation is not the only cause for mutation.) The number of mutants appears to be directly related to the amount of radiation; that is, doubling the dose doubles the number of mutants. It is presumed that the radiation would have exactly the same importance and effect no matter how low the radiation level. It should be pointed out that we have no data below 25 roentgens and that extrapolations to very low levels are made on theoretical grounds.

It has also been generally accepted that the radiation effects on the extent of mutations are cumulative. That is, whether the dose is given at one time or distributed over long periods of time, the effects are exactly the same. Although

these data appear sound, they may still be considered incomplete and there are minor discrepancies which have appeared and which may require some elaboration. There is also reason to discuss the place of the production of mutations compared with the general mutations that are being retained in the genetic pool.

The radiation dose necessary to double the mutation rate appears to be about 50 roentgens. It should be clearly understood that this is an estimate, and competent geneticists have submitted proposals from 5 to 150 roentgens.

It is known that there are many diseases of heredity (that is, genetic origin) which are almost certainly the result of mutants and may therefore be examined in the same light as mutants due to radiation. Since these may be retained in the pool because of the amelioration of the rigors of selection, it would be possible to assess all of these mutants in terms of roentgens. Therefore, a better estimate of the total hazard as a result of low doses of radiation would be possible.

It appears that most mutations appear to be of the recessive variety which would therefore, in effect, not permit their immediate recognition or elimination until after many, many generations. This means that the mutant will become widely disseminated in the genetic pool. It also means that the radiation received by a small segment of society may be of little consequence since the radiation to the total population would be roughly the ratio of the total population to this small segment. The genetic effects are best surveyed from the point of view of its effect on the whole population and, generally speaking, the genetic effects become significant when delivered to either the whole population or large segments of it.

I am inclined to make these observations from the point of view of long-term effects of radiation—that is, the production of tumors, leukemia, and the decrease in longevity.

All data presented at the present time are either presumptive or speculative for very low doses. They rest in hypotheses derived from the theoretical aspect of dose effects at high levels. I believe there is sufficient uncertainty so that it would be unwise, and in fact nonscientific, to make conclusive decisions on the basis of these extrapolations.

With respect to the genetic effects, which have been extensively studied by biologists, there are sufficient uncertainties even in these data so that it is not possible to accept them as entirely unassailable. These include the fact that data at low levels do not exist, that data are confined at present to Drosophila and to a few small mammals such as mice, that the mutation rate due to ultraviolet radiation appears to be nonlinear, and there is reason to believe that some of the energy transfer with ionizing radiation is in part of the same character as that with ultraviolet radiation. Man has existed since time immemorial in a sea of radiation where fairly large differences because of altitude and special geographic places also are present. It is difficult to reconcile some of the conjectures to be made at very low levels with the natural radiation doses to which man has already been subjected.

To my mind, the problems of biologic effects at low doses are in essence these:

1. The data on the biological effects at low levels of radiation are by no means conclusive. At best they must be considered highly presumptive This suggests that extensive, carefully considered research is necessary.

2. Even if one assumes that the low-level effects of radiation are established, the problem of establishing the hazard and the risk rate at these levels has not yet been fully and properly evaluated. With specific regard to the fallout problem, it is my opinion that at the low levels which now appear to exist, no immediate decision on any vital problems is now necessary.

With respect to the general overall consideration regarding all-out nuclear warfare, a different order of magnitude is introduced and I must join with others in pointing out that this is fraught with the direst consequences, and that every effort must be expended to the elimination of nuclear warfare.

With specific respect to the fallout problem, it is my opinion that with the low levels which now exist, no precipitate alteration in our course is required. There are a number of organizations on radiation protection that are continually looking at this problem with representatives of all disciplines, and they are gradually modifying the acceptable levels wherever it is found desirable.

Representative HOLIFIELD. Before we hear our next witness, I would like to insert in the record a report from the Armed Forces Institute of Pathology.

(The report referred to follows:)

ARMED FORCES INSTITUTE OF PATHOLOGY,
WALTER REED ARMY MEDICAL CENTER,
Washington, D. C., May 16, 1957.

Subject: Statements for congressional hearings.

To: Chief of Research and Development, Department of the Army, Washington, D. C.

(Attn. Chief, Atomic Division.)

The following report is submitted in accordance with a verbal request to the Director of the Armed Forces Institute of Pathology from Lieutenant Colonel Ransom of the Research and Development Office of the Department of the Army, May 14, 1957. The time limit of 24 hours for the preparation of such an extensive report, and the absence on TDY of the Chief and Assistant Chief of the Section on Radiobiology, Armed Forces Institute of Pathology at the Nevada test site on Operation Plumbob 4.1 necessarily resulted in some limitation on presentation of material requested which under more favorable circumstances could possibly be more fully covered. The discussions and answers as presented represent a combined effort of the professional staff of the Armed Forces Institute of Pathology with some assistance obtained from Naval Medical Research Institute and Walter Reed Army Institute of Research.

W. M. SILLIPHANT,
Captain, MC, USN, The Director.

CONCERNING TOPIC IX

A detailed discussion of the occurrence of strontium 90 and cesium 137 in the atmosphere and its uptake and behavior in man is contained in the remarks prepared by Dr. Willard F. Libby, Commissioner, United States Atomic Energy Commission, for delivery before the spring meeting of the American Physical Society, Washington, D. C., April 26, 1957. A copy is attached (see p. 1519). These findings have also been discussed and confirmed by Drs. J. L. Kulp, W. R. Eckelmann, A. R. Schulert (Strontium 90 in Man. Science, 125, p. 219, February 8, 1957). However, Dr. Lapp (Science, vol. 125, p. 933, May 10, 1957) criticizes some of these conclusions, and points out some pertinent factors for consideration. His critique is attached (see pp. 694, 704).

CONCERNING TOPIC X

SOMATIC EFFECTS—PATHOLOGY

A. Distinction must be made between the somatic and genetic effects of radiation

The genetic cells carry on from generation to generation the damage which has been received. The somatic cells receive the injury but this is not transmitted from one generation to another. The effects of high level radiation may be manifested not only immediately but also after a delayed period. There are also effects from a low level of radiation and some organs are more readily injured than others.

B. Early effects of exposure of animals and man to external radiation

1. *Gama and X-radiation.*—Syndrome of radiation sickness. Individuals receiving doses of total body radiation can probably be best divided from a standpoint of prognosis according to the clinical signs and symptoms they present. This is particularly true because of individual variation in the response of different people to the same dose of irradiation. Roughly, casualties may be grouped into those in which survival is improbable, possible, and probable.. There is, however, no very sharp line of demarcation among the groups. The signs and symptoms have been described for the Japanese casualties at Hiroshima and Nagasaki in a report by Liebow, Warren, and DeCoursey in the American Journal of Pathology and in a report entitled "Some Effects of Iionizing Radiation on Human Beings" involving particularly the Marshallese casualties. In doses of more than 3,000 roentgens one may encounter a hyperacute reaction within an hour whereas in the range of about 3,000 to 2,000 roentgens nauseau, vomiting, and some diarrhea and fatigue may be the initial reaction in 2 to 4 hours after exposure. In individuals receiving doses between the range of 2,000 down to 800 roentgens there may be a period of relative well-being following the initial reaction for a few days and then a gradual return of

anorexia, malaise, severe diarrhea, thirst, fever, delirium, and leucopenia. In individuals between 800 and 300 roentgens this reaction may come in about 2 to 3 weeks with acute bone marrow failure, ulceration of the gastrointestinal tract, epilation, and bacterial infection. A subacute reaction consisting of subacute marrow failure, subacute infection in the lungs, brain, and bowel and general malnutrition may manifest itself in about 6 weeks after exposure in patients receiving 350 to 250 roentgens. In those receiving less than 250 roentgens and in some survivors from doses in the lethal range, there may be a chronic reaction of varying degrees extending for a period of months or longer of malnutrition, chronic anemia, premature aging, leukemia, and possibly neoplasia. The above acute syndrome varies with the geometry of the source of radiation in relation to the exposed person.

(*a*) Marshallese: See reference.

(*b*) The Los Alamos incidents referred to under X, B, 1, b are covered in a single entire issue of the Annals of Internal Medicine February 2, 1952.

2. *Beta radiation—Beta burns.*—As long as only very penetrating radiations are involved in exposure of the entire body, skin injury would rarely be a problem, because a dose sufficient to permanently affect it would kill the patient before dermatologic lesions were of any concern. Epilation is an exception to this statement since it was present, though only temporarily, in some of the Japanese atom-bomb victims. During fallout from bomb clouds, however, radioactive particles may settle on the exposed skin of anyone outdoors, and the hazards of beta particle radiation burns are added to the effect produced by penetrating gamma rays. Beta particle burns resulting from fallout first came into public prominence with the announcement that some of the inhabitants of the Marshall Islands were exposed to such a hazard during the 1954 weapons-testing program. However, the problem of fallout was not a new thing to those charged with the responsibility of conducting tests of nuclear weapons. At the time of the first nuclear detonation at Alamagordo, N. Mex., a number of cattle about 10 miles from the blast received fallout on their backs. The fine particles were retained by the hair, and in a few weeks epilation and blisterlike lesions occurred. The lesions healed much like ordinary thermal burns, and the hair grew again, but the original red color was replaced by grey or white. Late effects of this exposure have recently been reported in studies conducted at the AFIP.

(*a*) Marshallese: In the Marshallese group individuals were exposed to gamma and beta radiation. The injuries due to beta burns were local and confined to the areas of contact. The reaction manifested itself by initial tingling and itching at the time of exposure, followed by erythema and edema in a few hours, lasting for 2 to 3 days. There was then a latent asymptomatic 3- to 5-day period with a return of secondary erythema with vesicle formation. Drying and desquamation takes place in about 3 weeks and the individual then may enter a chronic phase with some atrophy of the involved parts taking place. Where both types of radiation occur concomitantly, the gamma radiation generally overrides the beta in clinical significance.

The effects of ionizing radiation amongst the Marshallese has been extensively covered in the report Some Effects of Ionizing Radiation on Human Beings from the Naval Medical Research Institute, Bethesda, Md.; United States Naval Radiological Defense Laboratory, California; and Medical Department, Brookhaven National Laboratory, Upton, N. Y.; United States Atomic Energy Commission, July 1955. Values for gamma and beta radiation could only be approximated but there was a high enough dose on the skin to produce lesions. The estimated "point source" doses were:

Rongelap, group I, 260 r.

Uterik, group IV, 20 r.

Some of the patients showed acute symptoms of diarrhea and vomiting and itching and burning of the skin in group I (Rongelap) but none in group IV (Uterik) showed these symptoms. Biopsies were taken of the skin at various stages. These showed changes typical of radiation reaction. Ultimately there was complete restoration of the skin.

(*b*) Other examples: Skin lesions, acute, chronic and neoplastic were one of the earliest hazards to be recognized in human beings exposed to low energy radiation. Human casualties from ionizing radiation have been of increasing concern since the turn of the century. These include in addition to skin lesions, a higher incidence of leukemia among radiologists than among the general population. The occurrence of cataracts among early workers with cyclotrons, the

high incidence of cancer of the lungs as an occupational hazard among certain miners in Czechoslovakia, and the bone cancers that occurred in watch dial painters in this country.

(c) The early effects of internal radiation are dependent upon the amount, type, and area where material is deposited

If the material is insoluble and taken into the gastrointestinal tract, it might produce only local irritation of the intestinal tract but not be absorbed within the body economy. Another example would be in giving I-131, the early manifestations of which would be some soreness of the thyroid and hematopoietic changes (approximately 2 to 3 weeks). However, this would require a large therapeutic dose.

(d) Criteria include

Half life (the physical and biological half lives), body utilization, solubility and excretion.

(e) The degree to which late effects, readily produced in animals by single "massive" doses of total body ionizing radiation, may turn up in survivors in Japan is still under investigation

Such effects include the occurrence of tumors in various organs after long latent periods following a single exposure to total body radiations in the lethal dose range; genetic mutations that affect subsequent generations; and aging. Such injuries are obviously far more difficult to follow in man than in controlled laboratory animal populations. It is only very recently that quantitative data on genetic mutations have been extended from fruitflies to a mammal, namely, the laboratory mouse, and this may still be a long way from the problem in man. An increased incidence of myelogenous leukemia and radiation cataracts has been found in the followup studies of the Japanese to date.

In the course of radiotherapy, it seems that serious late effects can result from a single exposure or a series of exposures to X or isotopic radiations. Thyroid cancer has resulted in children being given X-radiation for thymic disease. Leukemia has also been reported in individuals receiving X-radiation for spondylitis or those receiving repeated I-131 for cancer. The increased incidence in leukemia in the Japanese exposed to nuclear explosions at Hiroshima and Nagasaki is the only example of this disease occurring in man after a single acute exposure of the entire body to ionizing radiation.

(f) General

Exposure of the entire body, or a major portion thereof, to significant amounts of penetrating ionizing radiation interferes with the proliferation of normally self-replenishing tissues essential to life, namely the bone marrow, and under certain circumstances, the small bowel epitheliu. Within the lethal dose range, most of the stem cells responsible for the continued replacement of these tissues are still capable of recovery, with survival being dependent upon the time and extent of regeneration. The acute radiation syndrome, therefore, is a clinical entity resulting from an action of ionizing radiation from which recovery is potentially possible. It is a diagnosis that includes the signs and symptoms that evolve following exposure of the whole body or a major portion thereof to penetrating ionizing radiation.

It has been estimated that the human bone marrow pours into the blood stream each day 1 trillion red blood cells, 10 billion granulocytes and 500 billion platelets. The epithelial lining of the small bowel of a rat is replaced every day and a half. In the human, the rate of replacement is not accurately known, but it is also quite rapid. The rate of cell division in these tissues, throughout life, is as high as that encountered in a great many malignant tumors. Interference with the continuous proliferation or replacement of these tissues results in a secondary aplastic anemia and damage to the integrity of the alimentary tract.

The sequelae of panhematocytopenia from any cause have been known for a number of years. They include (1) thrombocytopenic purpura, (2) anemia, and (3) agranulocytic infections.

Anemia is due to a variety of factors including (1) inadequate hematopoiesis, (2) widespread purpuric hemorrhage, and (3) increased destruction of red blood cells. Hemorrhage is most prone to occur at sites of injury due to radiation damage, accidental trauma, and physiologic activity. Huge numbers of extravasated erythrocytes return to the bloow stream via the lymphatic system and thoracic ducts. Many are phagocytized by macrophages. Increased destruc-

tion of red blood cells occurs, and leads to increased deposits of hemosiderin in the spleen.

Vincent's Angina is a common complication of agranulocytosis from any cause. Mechanical trauma and poor oral hygience invite septic ulcerations, particularly in the presence of agranulocytosis. The tonsils, as is well known, may serve as portals of entry for bacteria with the subsequent development of a bacteremia or septicemia.

Focal hemorrhages from radiation-induced thrombocytopenic purpura may be followed by septic ulcerations of the large bowel and the onset of diarrhea several weeks after exposure, even though the dose of radiation to the abdomen has not been sufficient to permanently interfere with recovery of the more radiosensitive small bowel. Such things as focal hemorrhages, delayed vascular reactions to irradiation, and to injured tissue, damage to the solitary lymphoid follicles and smoldering superficial infections contribute to the development of such ulcers.

Recovery of the small bowel epithelium generally occurs following exposure to total body ionizing radiation up to 100 percent lethal dose. Failure of recovery, however, may be an important factor in early deaths resulting from exposure to supralethal doses, or where the small intenstine is the principal site of injury.

1. In the various mechanisms of response of man to radiation the injury is caused by the energy imparted by the various ionizing radiations. This energy is dissipated in matter through excitation or ionization, depending upon the energy level of the radiation. The total ionizing action is related to the number of ion pairs formed per unit limit. This may be expressed as the density of ionization. Alpha particles have a high ionization density but a short range; beta particles a less dense ionization pattern but a range of a few millimeters in tissue and a few centimeters in air. Gamma radiation has a long range with the lightest ionization density. Neutrons have a somewhat shorter range than gamma rays. This is significant in that gamma and neutrons can penetrate with ease into the body from external sources. In contradistinction, alpha and beta particles are limited in such penetration from practically 0 for the alphas to a few millimeters through the skin for the betas. However, from an internal source, alpha emitters take on particular importance because of their unrestricted local activity over very long periods of time.

Certain effects of ionizing radiation on living cells in both plant and animal tissues have been clearly established for many years. These include (1) acute cell destruction, associated with nuclear vacuolization, rupture, and fragmentation; (2) a variety of chromosomal alterations and; (3) delay in division. Less well understood actions include (1) differentiations, aging and death of so-called vegetative intermitotic or stem cells; (2) effects which interfere with the action of humoral factors involved in the regeneration of certain tissues, including derivatives of the reticuloendothelial system; and (3) effects involving the cellular and noncellular immune responses of the organism.

2. Significance of different types of ionizing radiation in process: There are several important differences between lesions to be expected from penetrating radiation and from beta radiation from fallout particles. Once the beta particles have reached the surface of the earth, they contribute to the general activity of the area, but do not endanger the skin surfaces to any extent, because they penetrate only a few millimeters of tissue and almost any covering affords some protection. Overexposure to gamma rays may be followed by the acute radiation syndrome, and death or recovery in a matter of weeks, while exposure to high levels of beta radiation may result in third-degree burns requiring long hospitalization and extensive skin grafting.

In early casualties due to fallout in the general vicinity of the nuclear weapon used, one is concerned chiefly with the "recoverable component" of radiation injury. With such fallout pattern, depending on meteorological conditions downwind from the site of detonation, the terrain, weapon, point of detonation, etc., time, intensity and quality factors of irradiation become as important for prognosis, as they are in formulating a radiation prescription for the treatment of malignant disease. From a research standpoint also, the recoverable component of irradiation injury appears to be the key to survival following total body irradiation.

3. Ionization is thought to result in the breakdown products of water in the presence of oxygen into OH, H, O_2H, and H_2O_2; with the exception of hydrogen, these are powerful oxidizing agents. As to the locus of the radiation effects, in cells, two theories are advanced. One, the target theory localizes the action with some vital component of the cells. The other, the indirect theory, relates more

to the general action of the breakdown products of water. Both types of action probably account for radiation injury. One of the most important cellular effects is enzyme alteration. This generally occurs by oxidization of the SH groups or by protein denaturation. There is also a reduction of nucleic acid synthesis and arrest of mitosis. The use of the terms direct and indirect effects of irradiation should distinguish whether one is speaking of a single cell or the whole organism. Thus, ionizing radiation effects on the small bowel epithelium are direct in the sense that they are not appreciably inflamed by shielding various portions of the body other than the area of small intestine irradiated. Such effects within a single proliferating mucosal crypt cell may be both direct and indirect, although the latter, presumably mediated by the production of certain highly reactive radicals, appear to be the most important.

Various tissues of the body respond quite differently, in terms of ultimate effect, to the same cumulative dose of irradiation—total body and otherwise—fractionated in different ways. (See also data by Nachmansohn and Cotzias and Serlin under X, Bl.)

4. As a general rule, the sensitivity of a call to radiation varies as the mitotic activity and inversely as the degree of differentiation. Ranging from the most sensitive to the least sensitive, are the lymphocytes, erythroblasts germinal epithelium of tastes, myloblasts, intestinal crypt epithelium, ovarian germinal cells, basal layer of skin, connective tissue, liver, pancreas, kidney, bone, brain, nerve, and muscle. It is important to distinguish between radiosensitivity and radiocurability as well as the biological effect under consideration.

5. Effects of the whole organism.

(*a*) There is a wide difference in susceptibility of various animals to total body irradiation. The approximate LD 50/30 doses of total body radiation are as follows:

	Roentgens		*Roentgens*
Guinea pig	250	Rat	590
Dog	300–430	Mouse	500–650
Swine	420	Burro	580–780
Man	450 (estimated)	Rabbit	790–875
Monkey	500 [1]	Chicken	1,000
Sheep	520	Turtle	15,000

[1] For servival period of 67 monkeys at various gamma radiation doses see Effects of Barium^{140}–Lanthanum^{140} etc., under B.1. For recent review of the Effects of Radiation in Mammals, E. P. Cronkite and V. P. Bond, American Review of Physiology, vol. 18, 1956.

The difference in the lethal dose of total body irradiation upon various mammalian species: guinea pig, 200 roentgens, rabbits, 800 roentgens, has been directly correlated with degree of the recovery of delay in bone marrow produced in the particular species involved by such dose.

(*b*) Micro-organisms vary tremendously in their susceptibility to radiation. To destroy all bacteria in milk, for example, requires at least 750,000 roentgens. Tobacco mosaic virus requires 1,800,000 roentgens.

(1) Position of man: There are no exact data. The LD50 figure of 350 roentgens proposed from the Marshallese contrasts with a commonly quoted value of 400 roentgens or 450 roentgens. (Handbook of Atomic Weapons for Medical Officers prepared by the Armed Forces Medical Policy Council for the Army, Navy, and Air Force, June 1951), and a recent evaluation of the Japanese World War II casualty data something in figures well bove 400 to 450 roentgens for the immediate radiation from the bomb. (See Marshallese report).

6. The clinical syndrome in man of radiation injury in the sublethal and lethal range presents a fairly uniform hematopoietic pattern. In the sublethal group, there is an early and profound drop in lymphocytes with the neutrophil count showing an initial rise in 12 to 48 hours and then falling to pre-exposure level with a maximum drop from 5 to 6 weeks. Platelets start to decrease in a few weeks with a maximum low in about one month. During the first few weeks the hematocrit falls off only slightly if there is no bleeding. In the lethal ranges the same course of events occur but are markedly acceleraed and of greater intensity. The platelets drop off by the 4th day and completely disappear by the 10th. This general hematopoietic depression ties in with the subsequent bleeding and infection susceptibility. In the delayed effects the shortening of life span may result from such general factors as lowered immunity, damage to connective tissue, and premature aging. The question of specific tissue damage is indicated by the increased tendency to leukemia and skin cancer in certain exposed individuals. However, the carcinogenic factor is not too well established in humans.

For syndrome of nervous symptoms, see joint report of Hiroshima and Nagasaki casualties, etc., by Shiraki et al., under X, B,1. Also in National Academy Sciences report, 452, pages v-5–v-62.

G. Relationships of damage mechanisms to dosages

1. Production of leukemia and neoplasms (under mechanisms and response of man to radiation and radioactivity) exposure to ionizing radiation has been generally accepted as a leukemogenic factor in man (Kaplan, H. S., Cancer Research, 14, 535, 1954).

The high incidence of leukemia in radiologists, 8 to 10 times the incidence in nonradiologists has been widely accepted as evidence of this factor (Ulrich, H., New England Journal of Medicine, 234: 45, 1946). Further evidence has been the cases of leukemia and malignant epithelial lesions (Hepatomas) many years after the diagnostic use of Thorium dioxide (Thorotrast).

More recent evidence is the preliminary report from England in 1956 on the apparent increased incidence of leukemias in children following exposure to weak irradiation received through prenatal diagnostic pelvimetry (Stewart, A., Webb, J., Giles, D., and Hewitt, D., Lancet 2: 447, 1956).

Aplastic anemia: It is well known that the atomic bomb victims that survived the blast and were exposed to extensive radiation died with aplastic or hypoplastic bone marrows. The sequence of the morphologic changes in the bone marrow have clearly been described by Liebow, Warren, and DeCoursey (American Journal of Pathology 25: 853, 1949). In experimental animals evaluation of bone marrow radiosensitivity indicates a variation in degree of sensitivity of the hematopoietic elements with the granulocytic and erythroid elements being most sensitive and fat cells and reticulum cells the least sensitive and even quite radioresistant (Bloom, M. A., and Bloom, W., Journal of Laboratory and Clinical Medicine, 32: 654, 1947). However, more recent studies have indicated that erythropoietic elements are definitely less sensitive than granulocytic (Valentine, W. N., and Pearce, M. L., Blood, 7: 1, 1952).

The use of repeated large whole-body irradiation exposures has been studied by Valentine, Pearce, and Lawrence in the cat using 4 exposures of 200 r over a period of 1½ years. Although the exact L. D. 50/30 days is not known, their preliminary work indicated that probably was in the 300 to 350 r range.

Nevertheless, a single dose of 200 r represented a severe hematologic insult. Recovery occurred within 30 days following each exposure with very little detectible marrow damage after four exposures. (Valentine, W. N., Pearce, M. L., and Lawrence, J. S., Blood 7: 14, 1952.)

For a population of 100 million with a lifespan like that of the United States, each absorbed roentgen of whole-body radiation would result in about 6,000 cases of leukemia during their life time, while one-tenth the "maximum permissible dose" of Sr^{90} would result in 35,000 cases. (E. B. Lewis, Leukemia and Ionizing Radiation. Science, 1957, 125 in press.)

GENETIC EFFECTS

H. The nature of genetic effects: Studies, beginning with Mendel, demonstrated that the characteristics of living things were inherited following certain specific laws. Animal-husbandry men and farmers knew most of this but could not interpret the genetics laws properly because of ignorance and lack of information concerning genes and the requirements for expression of inherited characteristics. The germ cells containing only a single set of chromosones which in turn carry only a single set of genes transmit the characteristic of one parent to the child. The child has a double set of chromosones and genes consisting of one set from each parent. Since the characteristic for one parent may be dominant over that of the other, the child will show a mixture of characteristics; some from one parent, some from the other, and some which were common to both parents. Studies with plants, insects, and animals have demonstrated the accuracy of these concepts.

Because there are so many genes and so many variations among the genes for the same characteristic, there is considerable opportunity for variation which in turn permits opportunity to meet changes in the environment. There is still another mechanism which acts as a safeguard to allow the various species to change and thus adapt themselves to severe and marked alterations in the environment. This mechanism is called mutation. It consists of an abrupt, spontaneous change in a gene, producing a change in a recognizable characteristic. Most mutations are detrimental to the species and would be of value

only if there was a considerable change in the environment. It has been estimated that approximately 1 in 10,000 germ cells will undergo such mutation.

Frequency of tangible genetic effects as given by NAS report, i. e., mental defects, epilepsy, congenital malformations, neuromuscular defects, defects in vision or hearing, cutaneous and skeletal defects, or defects in the gastrointestinal or genito-urinary tracts, make up about 4 to 5 percent of all the live births of the United States. Of these about 2 percent are genetically caused. But this is not the natural mutation rate, which also includes lethals, changes in fertility, life span, etc., which are hard to detect and other nonharmful changes (eye color, etc.). Therefore it may be as Muller suggests, more like 1 in every 5, or 20 percent.

Recognized causes for natural mutation are temperature, chemical substances (particularly azone), and radiation. Again based on experiments with insects and animals it has been estimated that radiation equivalent to 30 to 80 r, whole-body dose, will double the normal spontaneous mutation rate. Further it has been demonstrated that the time over which the radiation is received does not affect the mutation rate.

Russell's studies on mutation of seven genes in mice show that about 30 r delivered to immatured germ cells constituted the doubling dose. There is probably not much higher in man, it may even be lower.

Since man exhibits a longer life span than mice and Drosophilia, it is likely that more of the spontaneous mutations are due to background radiation. If it were equal to it (3 r) then the doubling rate would also be 3 r. It is more likely that it is about 3 times as large (10 r) as recommended by the NAS reports.

The frequency of point mutations increases linearly with radiation dosage. In Drosophilia this has been demonstrated for a range from 25 r to 6,000 r. In certain plants this is extended down to 5 r. In mice this has only been tested from 300 to 800 r, but there is no indication that it does not hold outside this range. There is no sign of a threshold below which mutations are not produced, but rather even the lowest are proportionately mutagenic, and all doses are additive or cumulate in effect.

Because gene changes are inherited and because it is very rare for genes to mutate back, the occurrence of a mutation is thereafter inherited until the end of that cell line. Consequently, the effects of mutation accumulate within the population. With random matings these genetic changes become dispersed among the population. If the mutations are detrimental they are likely to cause decreased viability and ultimately death when accumulated in the population to such an extent that both parents transmit the detrimental character to the child. In effect this eliminates the mutant from the population. Ultimately a level is reached whereby for each new mutation arising an old mutant accumulated in the population will be eliminated.

Because of these reasons it has been believed by one group of investigators led by Muller that any increase in radiation can only be harmful and ultimately will lead to degradation and degeneration of the race. However, this will require many generations before such effects could become apparent. A smaller group believes that there are certain inherent safeguards which would protect the species by decreasing mutation rate in response to radiation.

Sturtevant of the California Institute of Technology has calculated that, if the irradiation from fallout increases at its present rate, it will produce some 70 children a year carrying a mutation. This estimate he adds may be too low and, in fact 7,000 may be a better estimate. This has no noticeable impact statistically, that is, about 2 percent (150) will actually show changes from the normal. If compared to the 4 million born yearly and 40,000 defective ones at birth we need not be concerned about the effect of fallout on the future of the people at large or on mankind. Yet if the statistical approach is not used 150 individual newborn children each year will be affected.

Some of the current problems in this field are discussed in the following articles:

Crow, James F., The Estimation of Spontaneous and Radiation-Induced Mutation Rates in Man, from Eugenics Quarterly, vol. 3, page 201, 1956.

Crow, James F., Possible Consequences of an Increased Mutation Rate, from Eugenics Quarterly, in press.

Glass, H. B., The Induction of Mutations with Radiation, talk delivered at International Agency for Peaceful Application of Atomic Energy, Brookhaven National Laboratory, May 15, 1957.

Stern, Curt, Genetics in the Atomic Age, from Eugenics Quarterly, vol. 3, page 131, 1956.
Muller, H. J., Potential Hazards of Radiation, from Excerpta Medica (Amsterdam) in press.
Muller, H. J., Damage from Point Mutations in Relation to Radiation Dose and Biological Conditions, in press.

L. Concepts and definitions for standards pertaining to external radiation effects are covered in Relative Biological Efficiency of Different Ionizing Radiations, John W. Borg, National Bureau of Standards Report 2946, December 30, 1953.

M. Standards for internal radiation effects:

1. Reference is made to the report of the Subcommittee on Toxicity of Internal Emitters as given in Pathologic Effects of Atomic Radiation, National Academy of Sciences—National Research Council publication 452.

Also reference is made to the report Tentative Recommendation of the NCRP for the Maximum Permissible Levels of Radiation to Man, a copy of which is attached.

2. For methods of determining total accumulated doses and dose rates from external radiation, see Doses and Dose Rate Cures, AFSWP Manual No. 99.

N. ———.

SPECIFIC QUESTIONS FOR DISCUSSION

A. All low level effects are not extrapolations from high level effects, (for example see studies by E. Lorenz). Such extrapolations would be hazardous. However, further studies on low-level effects are particularly important since the explosion on March 1, 1954, of an experimental thermonuclear device at the United States Atomic Energy Commission Eniwetok Proving Grounds in the Marshall Islands.

B. There are quite definite distinctions between temporary and permanent (long-term) damages, and between repairable and irrepairable damage. The problem of certain long-term damages may be complicated by sequelae from effects upon tissues other than the one(s) in which the most serious lesion(s) may ultimately appear, as in the development of certain neoplasms. This has been demonstrated in the case of malignant tumors arising in the thymus following irradiation by Kaplan, and may be true also for certain other types of neoplasms arising many years after exposure, as an example, in the skin. While repairable effects are well known, the differential sensitivity of anatomical units of an apparently, morphologically, homogenous tissue may result in incomplete recovery of a sufficient number of components after high doses to result in death of the organism. Recovery of self-replenishing tissues essential to life, such as the bone marrow and small intestine (when the abdomen is the principal site of injury and after supralethal doses of total body radiation) may be sufficiently delayed until sequelae, such as those associated with panhematocytopaenia result in death even though in the case of the bone marrow recovery may still occur if such complications can be controlled.

C. * * *

D. The effects on behavior in Hiroshima and Nagasaki casualities who died during the period of 16 to 69 days is mentioned under Joint Report—Effects of Atomic Radiation on the Brain of Man, Etc., by Shiraki, et al., under X, B–1. There was little evidence of changes in mental posture, personality, and intelligence in those who died during the first 3 months after exposure. Under such conditions the dose level was great enough to cause death from anemia and other factors, but was insufficient to affect directly the brain. Japanese physicians have stated that many patients who survived the bombings have shown no neurological disabilities but have complained of generalized weakness, easy fatigability, and nervousness for years after the bombings.

E. To date we are probably limited for practical purposes in the event of mass casualities due to exposure to ionizing radiation to procedures which will (1) reduce the dose received by such things as shelter, evacuation, clothing, bathing, washing down ships of the fleet, etc.; (2) reduce and combat complications such as burns, indirect injuries from blast effects, and infection; and control the sequelae of panhematocytopaenia, and disturbances in water and electrolyte balance, by procedures in general use for such syndrones from any cause. The possibility of adding to this armamentarium by more specific therapeutic measures, including both humoral and cellular factors appears probable from research to date, but has not been consummated.

F. Unless all radiological factors are reported, and radiation procedures such as fluoroscopy standardized as far as practical, a record of the number of roentgens received by each person during his lifetime would probably not be very meaningful. For example, to record the fact that on a film badge a patient received 10 roentgens, per se, is no more informative than a statement that he was given 10 milliliters of a substance intravenously without indicating the concentration of the solution.

G. The total estimated dose rate to gonads from natural sources of radiation both internal and external is 0.095 roentgens per year. In addition it is estimated that diagnostic radiology contributes 22 percent of the above natural radiation dose. Occupational exposure in radiology and industry adds at least another 1.6 percent of the natural radiation dose. (The Hazard to Man of Nuclear and Allied Radiation, presented to the Lord President of the Council to Parliament by Command of Her Majesty, June 1956.) H. (The numbering of the questions skips from H to J).

J. * * *

K. Radioiodine acts principally on the thyroid, but a possible relationship to leukopenia and anemia has been suggested. The doses and expected effects are as follows:

(*a*) 1 or 2 milliocuries I^{131}: This is the lowest amount that will cause transient alteration of physiological activity of the thyroid. No recognizable histologic changes would be expected.

(*b*) 10 to 15 millicuries I^{131}: This amount will cause a mild transient decrease of thyroid activity, probably detectable only by laboratory tests. The depression may last a few months. Histologic alterations, if any, would be in the form of mild fibrosis and slight los of follicular epithelium.

(*c*) 35 to 75 millicuries I^{131}: Usually given in fractional doses, this total amount can be expected to produce definite clinical hypothyroid state for between 6 and 12 months. Histologically, there would be varying degrees of fibrosis and follicle destruction.

(*d*) Two courses of 35 to 75 millicuries I^{131} can be expected to produce almost complete cessation of thyroid function with severe myxedema. The duration of the myxedema cannot be predicted, as the patients tend to develop thyroid activity over the course of a few years. Histologically, one would expect virtually complete fibrosis of thyroid with a few surviving distorted epithelial cells and possibly a few distorted follicles. Eventually, some regeneration of follicles might occur. Even though there may be widespread destruction of thyroid, the parathyroids are unaffected.

(*e*) 1,200 to 1,500 millicuries: This total amount has been given over a period of several years to a few patients. Leukopenia and/or anemia has sometimes developed and been attributed to the radiation effect or circulating I^{131}, but there is no proof that the hematologic changes were due to I^{131}. Amenorrhea has been reported, but there is no proof it was the result of I^{131}.

Cs^{137}: There is no evidence so far that Cs^{137} has any unusual biological properties. It does not seem to localize in bone.

C^{14}: This is eliminated fairly rapidly (about 97 percent in 3 or 4 days) from the body, largely as CO_2. It does not localize in bone.

L. * * *

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Biographical Sketches of Witnesses Who Contributed to Statement by Armed Forces Institute of Pathology

ELSON BOWMAN HELWIG

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Professional education: Indiana University Medical School, Bloomington, Indianapolis, Ind., B. S. June 1930, M. D. June 1932.

Internship: City Hospital, Indianapolis, Ind., rotating service 1932–33.

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Certified by the American Board of Pathology: 1938.

Membership in Professional Societies: College of American Pathologists, Washington Pathologic Society, American Association of Pathologists & Bacteriologists, American Society of Clinical Pathologists, American Association for Cancer Research, Massachusetts Medical Society, Baltimore-Washington Dermatological Society, American Academy of Dermatology and Syphilology, International Academy Pathology.

Teaching associations and appointments with professional schools: Indiana University School of Medicine, assistant surgeon pathology, 1933–34: Western Reserve University Medical School, demonstrator, pathology, 1934–36; Washington University School of Medicine, instructor, pathology, 1939–42; Washington University School of Medicine, assistant professor pathology, 1946–47; George Washington University School of Medicine, professorial lecturer, 1947.

Military service: Army Medical Museum, 3 months, 1942; Chief of Laboratory Service, Bruns General Hospital, 1934; Chief of Pathology Branch and executive officer, 18th Medical General Laboratory, and consultant in pathology, Pacific Ocean area, 1944–45.

Present occupation: Senior pathologist at the Armed Forces Institute of Pathology; Chief of the Division of Pathology; Chief of the Pathology Branch; Chief of Derman and gastro-intestinal pathology.

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Representative HOLIFIELD. Our next witness is Dr. Austin M. Brues, of the Argonne National Laboratory, director of the Biological and Medical Research Division since 1946, and delegate to the U. N. Radiation Committee.

All right, Dr. Brues.

STATEMENT OF DR. AUSTIN BRUES, DIRECTOR, BIOLOGICAL AND MEDICAL RESEARCH DIVISION, ARGONNE NATIONAL LABORATORY [1]

Dr. BRUES. Thank you, Mr. Chairman.

I do have a short prepared statement which I intend to read in its entirety.

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[1] April 25, 1906. A B. Harvard University 1926; M. D. Harvard Medical School 1930, Med. Resident, Huntington Mem., Hosp., Boston, Mass., 1930–31; House Officer, Mass. Gen. Hosp., Boston, Mass., 1931–32; Asst. in Med., Harvard Med. Schl., Boston, Mass., 1932–34; Grad. Asst., Mass. Gen. Hosp., ibid., 1932–34; Asst. Phys., Huntington Mem. Hosp., ibid., 1932–37; Rsch. Fellow in Med., Harvard Med. Schl., ibid., 1934–35; Instr. and Tutor in Biochem. Sci., Harvard Coll., ibid., 1934–42: Moseley Traveling Fellow, Harvard Univ. and Royal Cancer Hosp., London, England, 1935–36; Grad. Asst., Peter Bent Brigham Hosp., Boston, Mass., 1936–37; Instr. in Med., Harvard Med. School, ibid., 1936–37; Assoc. Phys., Huntington Mem. Hosp., ibid., 1937–41; Assoc. in Med., Harvard Med. Coll., ibid., 1937–42; Ward Visit, Boston City Hosp., ibid., 1938–39; Freshman Advisor, Harvard Coll., ibid., 1939–42; Jr. Assoc., Peter Bent Brigham Hosp., ibid., 1940–41; Intern, Army Induction Center, ibid., 1940–44; Assoc. Phys., Peter Bent Brigham Hosp., ibid., 1941–42; Responsible Investigator, Office of Sci. Rsch. and Develop., ibid., 1941–44; Asst. Prof. of Med., Harvard Med. Schl., ibid., 1942–45; Asst. Phys., Mass. Gen. Hosp., ibid., 1942–45; Sr. Biol., Metallurgical Lab., Univ. of Chicago, Chicago, Ill., 1944–46: Assoc. Prof. of Med., Dept. of Med. and Inst. of Radiobiol. and Biophysics, ibid., 1945–52; Prof., 1952—; Sr. Biol. and Dir., Biol. Div., Argonne Nat'l. Lab., Lemont, Ill., 1946–50: Sr. Biol. and Dir., Div. of Biol. and Med. Rsch., ibid., 1950—. American Assoc. of Anatomists: A. A. A. S.: Amer. Assn. for Cancer Rsch. (Pres. 1954–55): Amer. Physiol. Soc.; Amer. Soc. for Clin. Investigation; Assn. for Study of Internal Secretions; Assn. of Amer. Phys.; Cent. Soc. for Clin. Rsch.; Inst. of Med. of Chicago; Soc. for Cell Biol.; Soc. of Exptl. Biol. and Med.; Tissue Culture Assn.; Radiation Rsch. Soc. (Pres., 1955–56). Member of United Nations Scientific Committee on the Effects of Atomic Radiation. (Submitted by witness.)

Representative HOLIFIELD. All right.

Dr. BRUES. I want to speak chiefly concerning the philosophy of setting and determining the permissible levels which Dr. Taylor spoke of earlier this morning, and what the true basis of our understanding of these is.

The presently accepted safe levels of radiation and of radioisotope incorporation are based on a long history of clinical observation and experimental research. These levels have been determined on the basis of making the most pessimistic assumptions where knowledge is lacking and then introducing a factor of safety.

Where direct observations on human beings or suitable animals have been at hand, the practice has been to divide those levels which produce any detectable effects by 10 to arrive at a permissible level. It was on this basis that the permissible daily X-ray exposure of 0.2 roentgen to the whole body was reduced many years ago to 0.1 roentgen, and then, as a result of some further work which was done during the Manhattan District days, particularly having to do with the production of sperm in dogs given one-half roentgen a day, which showed dogs had some changes in the rate at which they produced a sperm, it was considered one-twentieth of a roentgen a day would be a safer dose.

The question then came up as to whether these levels had to be adhered to each day or whether one might not receive a week's dosage on Monday morning without any further effect than that incurred by spreading it through the week. While an acutely dangerous dose of radiation—say 500 roentgens—is less toxic if spread out over a week owing to the rapid recovery of the blood-forming tissues, there seemed to be good experimental evidence that the late consequences of low doses were rather independent of time, and so three-tenths of a roentgen per week was accepted. It seems quite likely that the whole yearly quota of 15 roentgens—which in itself produce no obvious effects—might as well be incurred on a single day, but three-tenths per week appears to be more practical, except for special cases such as might arise under civilian defense conditions, where a calculated risk might be acceptable.

That sort of thing has also been allowed for.

Ingestion or inhalation of radioactive substances presents a different problem. These sources of radiation may become concentrated in certain tissues and organs, and the greater part of the radiation energy, depending on type, may be given locally. The most striking example of this is the concentration of radioactive iodine in the thyroid gland, where half of the dose may be deposited in one one-thousandth of the body. We do not, unfortunately, for purposes of cancer treatment, know of any other such striking case of an extreme localization.

There have been two ways of solving this question. One has been to calculate the radiation dose in the "critical organ," that is, the organ with the highest radioactive concentration, and then to set levels of exposure such that the equivalent of three-tenths roentgen a week will not be exceeded. The other has been—and this is used where the bony tissues receive the highest dose—to compare the possible damage with that produced by radium in the human skeleton, since we have knowledge derived directly from the histories of persons who have been poisoned by radium through industrial exposure in the watch dial painting business or through administration of

radium as a drug in the days, 25 to 30 years ago, when it was thought that radium might be beneficial in certain conditions for which there was no known effective treatment.

Since no damage had been observed in patients who retained less than 1 microcurie of radium in the skeleton, about the amount in a radioactive watch, this was again divided by 10 and one-tenth microcurie was established as a permissible amount of radium. To this day, no detrimental effects have been seen in persons containing this amount of radium.

Since the preparations used to paint luminous watch dials and for some medical uses contained considerable amounts of other radioactive elements—specifically mesothorium—it has been suggested that pure radium may be less toxic than indicated here. This point is not settled, and a search is being made for other persons who may contain abnormal amounts of radium in order to improve our knowledge. In particular, it is becoming clear that a good number of persons may harbor more than 1 microcurie without detectable harm of any sort, and that the proportion who do suffer for a given amount is lower than was believed.

Since the first cases seen, and the majority, were found out because they had complaints which directed the attention of physicians to them, we see a selected group of people who met with the worst result; the well ones are much less likely to come to our attention.

This, again, I think, introduces somewhat a factor of safety in the question of how much radium is likely to produce serious effects on the human being.

These radium levels have been transferred to other radioactive materials as a result of comparing effects of radium on animals against those of plutonium or radioactive strontium. Plutonium turns out to be somewhat more toxic than would be expected from physical calculations of the radiation to bone, and this is apparently because plutonium is deposited near those cells which are active in bone growth.

Radioactive strontium 90 has been determined to be one-tenth or less as likely to produce bone tumors as radium for a given number of microcuries. On this basis, 1 microcurie of strontium 90 is considered as the equivalent of one-tenth microcurie of radium and, therefore, is designated as the maximum permissible level.

These levels were employed very successfully in the atomic-bomb project during wartime. Most of the workers remained very far below the permissible levels.

If you set up a level which is not to be exceeded, it happens, administratively, that things work out so that people get very much less.

There is the story of one individual on the project who attempted to receive his 10th roentgen per day because that is what he thought he was supposed to do. But, in general, nothing like this happened.

For practical purposes it is necessary to determine many more things than just the safe level of body content. We must also translate this into the amount which can safely exist in the air breathed and in the food and water ingested, in order to regulate these concentrations at a level which will not permit an excessive load to exist in the body. These are, then, the MPC's, or maximum permissible concentrations. This means we must use our best information as to how much is retained in the body from inhalation and from the digestive tract, and how fast it is lost from the body by excretory processes.

Many of these things have to be decided upon before the enormous amount of experimental work required for an exact answer can be carried out. There is no time here to discuss all this, but I can say that those committees shouldered with responsibility for such decisions always use the strictest possible assumptions, and, since several separate assumptions must be made—for example, how much in the air gets into the lung, how much in the lung is kept there until it gets into the circulation, how much of that is deposited, and how fast it is lost from the organ—as well as the relative effects of types of radiations from different elements, each of these considered in the worst light, we end up by multiplying a number of different factors of safety and are almost certain to come out with a level much lower than the correct one.

To give a few examples:

When tritium was first under consideration, it was noted that it has a remarkably short-range beta radiation, and nothing like it had been studied experimentally. So a factor of safety of 10 was introduced until it was shown that it acts about the same as the more familiar radiations, when this factor could be thrown out. Similarly, the strontium and radium levels were based on an early assumpion that they are lost from the bone according to a very slow process, which was measured on patients and animals a long time after its acquisition. This led to very low levels being recommended in water. It has since become known that loss occurs very rapidly at first, so that it requires about 10 times as much taken in to maintain a given level. The MPC's in this case have not yet been changed until complete study of the problem can be made, although the evidence is now fairly clear.

In another instance, a stringent level of radium in water was suggested unofficially, and we found that it was actually less than that in the drinking water of our laboratory. Had this been adopted, we would have been required to distill our own domestic supply before we could be permitted to let it flow off the grounds.

Of course, radioactive materials, as you have probably heard in the last few days, because of their special nature and the degree of development of our instrumentation, can be detected in relatively much smaller amounts than almost any other toxic material. This may be a large part of the reason for the disproportionate public concern about radioactivity relative to other noxious things.

As you are aware, there has been a general lowering of levels recently, since artifically produced radioactivity has become wider in its scope.

Here, we have to keep two things quite distinct. First is the problem of genetic effects, which will be discussed by others. The special features of these is that they seem to be produced without threshold: that is, any small amount of radiation will produce its proportion of changed genes; and that almost all of these are hidden and are perpetuated through generations till they come together accidentally through interbreeding. Thus, very stringent levels are recommended, but they do not refer to any individual but to the whole population; thus an average figure for the whole population is all that is to be looked for.

The other is concerned with the matter that we must not only consider, as was the basis of the original levels, a selected group of in-

dustrially exposed persons, but also many persons outside this group who might be close to installations where exposures could occur.

One asks, of course, why if a level is safe for one group, it is not for another. There are several reasons for this, none complete in itself. One is that the occupationally exposed group are selected, do their work voluntarily, are under medical control and are monitored. Another is that persons not in the atomic energy business may be in other fields of work which have their own peculiar hazards. Still another may be that there are more chances for an overexposure to occur. So that we might set the levels so that a considerable "overexposure," on that basis, would still not be an overexposure in the sense that it get to a level which would be within the potential danger zone. For these and other reasons, in one sense or another philosophical, we have adopted another safety factor of 10.

Mr. RAMEY. On our last point there, about your safety factor of 10 with respect to strontium 90, would the fact it applies mostly to the takeup of strontium 90 as it affects persons that it would be more as it applies to children, and therefore a lower factor when you go from an occupational group to a population group to take into account the bone-forming period?

Dr. BRUES. Well, this question has been raised. Actually I do not know of evidence that the skeleton of the child is more sensitive, except with respect to the fact that if one starts as a child and continues to an adult, he puts more of the material away. This, I think, has already been taken into consideration. We could still have more evidence on this, but data I have seen does not suggest the child at these low levels, where not stunting his growth, is going to show any more results than certain total amounts for others.

Representative HOLIFIELD. It is a fact that the bones of a child are growing and accumulating more cells at a faster rate of cell growth than the adult, is he not?

Dr. BRUES. That is true, yes; and on a given intake level, a larger total will be evident.

Another consideration which has led to extra safety is that of the fluctuating level of exposure. Where we have set conditions for exposure to external radiation we have allowed for such fluctuations. It seems equally reasonable for the level to say, radioactive strontium in water to exceed the MPC by 7 times 1 day a week; or for the point of disposal in a highly polluted river to exceed the MPC so long as it is diluted out before it reaches a point where it would conceivably be ingested—remembering also, that the MPC is based on the assumption of continuous intake for a lifetime. The same situation applies to shifting winds around a stack. For exadministrative reasons, it is therefore highly likely that conditions will be set which are much more stringent than those leading to a maximum possible concentration in personnel. It is most important to remember that that is what we are really concerned with, and that no legal culpability should be involved in an occasional fluctuation in the environment above that which would be one-tenth or one-hundredth of a dangerous level but only if it were kept up indefinitely.

The whole basis of the concept of a permissible amount, or level, by the way, rests on the assumption that there is a threshold; that is, that no harm will be done by smaller amounts. In genetics, we have reason to doubt that there is a threshold at all, so that the total popula-

tion average of exposure is set so low that it falls close to the natural variations in the natural radiation background.

Where the question is applied to other effects of radiation, such as longevity or cancer, we do not know whether they have thresholds or not. It has been suggested that they do not, but on the basis of very scanty evidence so far, and in no case is there information much below 100 r; and there are also good reasons from what we know about the nature of cancer to suspect that the hazard goes down faster than the insulating agent. An animal experiment to guarantee the existence of a human threshold below suggested off-site MPC's would be a prodigious undertaking and would drain off much of our talent from work which is really more basic to the problem. It would, moreover, detract both talent and public attention from problems of the same sort that seem, to me at least, as urgent.

For instance, millions of Americans now living will die of cancer of the lung due to something in the environment that we did not have a few decades ago. I once made a calculation by exactly the same means as are used in the calculations of MPC's, comparing lung cancer with radium cancer, and derived an MPC—occupational criteria—of 2.4 cigarettes a day. An off-site MPC would be 1 every 4 days. The only assumption made here was that cigarettes are the causative agent. If it is city smoke, this would have to be reduced in a similar proportion before the criteria used in determining permissible levels of radioactive substances would find it allowable.

Senator ANDERSON. What year would become a basis for this new item which has come into the picture? You say something about decades. How far back?

Dr. BRUES. These figures, of course, vary from place to place, and they have been coming up more slowly in the female than in the male. But in general there has been at least a tenfold increase in lung cancer since 1900, in the rates for age since 1910 up to the decade 1940–50. This is apparently still rising at a considerable rate, and, as I say, people are very much concerned about this problem.

Senator ANDERSON. Particularly with all the millions of dollars we are spending on cancer research. The more we study it, the worse it appears to get.

Dr. BRUES. This may be repeating my colleague slightly, but I will mention it again.

If we are to settle the question of threshold satisfactorily, I would say that we should carry out expanded studies on large populations of animals, but not rely on this to the extent of reducing the amount of basic work which will probably lead us sooner to a clear answer. I refer to many things, but chiefly studies on the nature and origin of cancer, the effects of radiation on cells, the nature of the aging process—for example, why a mouse lives little more than four score weeks and ten—and broad studies of medical and population statistics in relation to natural radiation.

Along with this are the whole unexplored fields within the medical and biological sciences, any one of which might turn out to be crucial to the radiation problem; recruiting and training good talent; and communication of scientific research findings.

As one who sits on various committees to discuss and, we hope, solve these problems, I am also impressed with the danger that more and

more of the best talent and time for the imaginative approach to these questions may be drawn away from the work and thought that they ought to be producing, into more and more debate over the same scanty knowledge.

May I just conclude with what might be a scientific parable, by pointing up the potential difficulties of the whole problem from an experiment done by the late Dr. Egon Lorenz.

Dr. Lorenz carried out the lowest-level experiment in chronic irradiation that has been done, giving mice a little over 0.1 roentgen daily throughout their life. He found, and thus confirmed an earlier experiment, that the irradiated mice developed more leukemias than those that were not irradiated, but that their average life span was almost 10 percent longer.

What a mouse would do in this case if he had a free choice, I am not sure.

Representative HOLIFIELD. Thank you very much, Dr. Brues, for your illuminating discussion.

Are there any questions?

Senator BRICKER. You would not want to conclude from that, if a human being was given 1 roentgen a day for his life, he would live 10 percent longer, would you, Dr. Brues?

Dr. BRUES. No, sir. Part of the parable was to say that I do not like to extrapolate animal experiments to man until they have reached a fairly good degree of ramification.

Senator BRICKER. I would not want to give him his free choice in that case.

Representative HOLIFIELD. The chart that Dr. Friedell gave in his statement showed that a lethal dose of 50 percent would apply to dogs, 350 roentgens; mice, 450 roentgens; monkeys, 500 roentgens. So that seems to be the nearest reaction as between your permissible dose of 400 roentgens to animals you are experimenting on. Is that right?

Dr. BRUES. That is right.

We do not know that the acute results run into the same proportions as late chronic effects.

Representative HOLIFIELD. There must have been some reason why they were in the same dose range, rather than rabbits, at 800, bacteria at 100,000 roentgens.

Dr. BRUES. The mammals do run, as far as acute kill goes, between perhaps 300 and 900. There is that degree of variation between the species, and this is just the amount that will kill them in a couple of weeks.

Representative HOLIFIELD. But you draw no parallel between setting the lethal dose of roentgens for man in that category?

Dr. BRUES. I would be afraid to.

Representative HOLIFIELD. Are there any further questions?

Thank you very much.

We will adjourn now until 2 o'clock, when we will have Dr. E. P. Cronkite, Dr. Edward Lewis, and Dr. Shields Warren as our witnesses this afternoon.

(Whereupon, at 12:45 p. m., the committee was recessed, to reconvene at 2 p. m., of the same day.)

Representative COLE. Mr. Chairman, I wonder if Dr. Warren would mind indicating the identity of these groups and committees of which he is a member, for the record, since it does not appear in his biography.

Dr. WARREN. Yes. I am the representative of the United States to the U. N. Scientific Committee on the Effects of Atomic Radiation. I am the Chairman of the Committee on Pathological Effects, of the National Academy of Sciences Radiation Group. I am also a member of the Committee on Genetics of the National Academy of Sciences. I am a member of the Advisory Committee on Biology and Medicine of the Atomic Energy Commission. Then there are various scientific associations with which I am also associated.

STATEMENT OF DR. JACOB FURTH,[2] PRESIDENT OF THE AMERICAN ASSOCIATION FOR CANCER RESEARCH (PRESENTED BY DR. SHIELDS WARREN)

Dr. WARREN. I think it would be appropriate in view of the fact that we have been hearing a very pertinent discussion of leukemia, to introduce at this point Dr. Jacob Furth's statement. He is an associate of Dr. Sidney Farber and myself, one whom I consider as probably the world's greatest authority on the experimental induction of leukemia. He say as follows:

FACTS

Radiation causes cancer and leukemia and other body changes, but it is also the best means of identifying and controlling many of them. Induction of neoplasms—by that meaning both leukemias and tumors—by radiations is a remote possibility and occurs rarely, while the benefits are immediate and usual; hence, radiation became a tool of medicine no physician or informed patient would want to be without. Most, if not all, increased hazard from radiations resulted from its medical use, a calculated risk well taken; it is steadily diminishing with recognition and dissemination of knowledge as to where the hazards lie.

SPECULATIONS

The statements that there is no threshold injurious dose to somatic cells, and every irradiation, no matter how small will cause cancer and leukemia, as is stated by some geneticists, are mere speculation. This applies also to the statement that even background irradiation is leukemogenic. The available facts allow argumentation of both sides. In my opinion, the statements that background irradiations will induce leukemia are contrary to observations and the reverse is more likely.

Reasons to assume that a threshold exists:

(*a*) All reported experiments on leukemia induction by irradiation have pointed to the existence of a threshold and none suggested the lack of it.

Dr. WARREN. I might say in addition that Dr. Furth has had access to all of these figures which you have seen on the chart here, and this is one of the conclusions he has come to.

(*b*) The complex mammalian host is capable of compensating for subtle damage. It has been shown that partial body irradiation is not conducive to leukemia development; the unexposed parts powerfully protect the exposed part. Thus, if direct hits cause mutation, humoral substances either counteract or reverse

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[2] Began experimental studies of leukemia in 1928; was first or second (if so in independent work) to publish induction of leukemia, ovarian, breast, lung, and pituitary tumors in mice by ionizing radiation. Presented experimental evidence that leukemia is allied to cancer and some leukemias are related to mutations. Has numerous publications 1930–57 on the subject, all essentially confirmed. Presently, is president of the American Association for Cancer Research. Recipient of high awards and fellowships in scientific organizations in recognition of scientific contributions. (From American Men of Science.)

their actions. Were it otherwise, leukemia among physicians and radiologists and others exposed to small doses of X-rays repeated over long periods of time would be manyfold that actually observed. Some radiologists receive thousands and tens of thousands of roentgens while the population at large receives a few r. of background irradiation in a lifetime. Similarly, if cancer induction is simply due to direct hit mutation with no threshold, one would expect a tremendous number of all kinds of tumors in medical personnel and others on parts exposed to radiation; for example, skin cancers on hands. The early radiologists who got such cancers had severe radiation burns with chronic ulcers in which the tumors arose. Some scientists even argue that the cancers arose from the nonirradiated adjacent skin. It deserves emphasis that cancer did not arise on the hands of tens of thousands of people receiving huge quantities in small doses over long periods.

(*c*) Similarly, leukemia development in experimental animals can be prevented by post irradiation infusion of marrow cells indicating that either direct radiation hit is not enough to cause leukemia or that body defense can somehow counteract this damage.

(*d*) The very idea that leukemia and cancers result from a direct hit mutation was never solidly proven and is being challenged recently. Newer evidence unquestionably indicates that some indirect factor plays a determining role in development of leukemias or tumors. Heavy irradiation of some organs can injure specific body regulatory mechanisms and cause cancer indirectly, not by mutation.

(*e*) In case of pituitary or ovarian tumor induction by irradiation, there is no such linear relationship between irradiation dose and response, as is characteristic for mutation. The reverse is true, and there is a clearly defined threshold which is that dose which markedly depresses the function of that organ—about 80 to 50 r. to the mouse's ovary, 30 μc of I–131 to mouse's thyroid.

(*f*) Human cells are eternally submitted to small doses of endless kinds of mutagenic agents; some are endogenous, as hormones; others are extrinsic, as chemicals in food, industry, drugs, et cetera. Even plastics and food dyes can cause cancer in animals under given experimental conditions. These, too, are believed to cause the neoplasm by somatic mutation, but I know not of a single human cancer proven to be caused by them. As to leukemia, many drugs and industrial chemicals injure blood forming organs and could be responsible for increased incidence of leukemia. We have yet to learn to what extent the endless number of potential carcinogens to which man is exposed contribute to development of neoplasia in man, alone and combined.

(*g*) Induction of leukemia in mice from radioactive substances as radiophosphorus and radiostrontium has been reported, as might be expected, from large doses of them, but these reports clearly show existence of a threshold.

RECOMMENDATIONS

(1) Since the medical hazards of radiation are worth taking and since these represent the bulk of radiation hazards, that thus far created by bombology, being a minor evil, should be considered as such. While it is agreed that the latter should be eliminated as expediently as possible with preservation of the safety of the free world, the burden of decision rests not with biomedical investigators, but with military experts. All biologists admit the potential hazards of all kinds of radiation and merely argue among themselves about the magnitude of the hazard.

(2) I wish to testify that support for long-term research has been, and still is, niggardly, and it is a disappointing struggle to undertake such research. I recommend liberal long-term support of creative scientists, and incidentally, more centers of knowledge in free institutions. Creative knowledge is our best defense.

Dr. WARREN. I appreciate your allowing me to read this statement of Dr. Furth into the record, Mr. Chairman.

Representative HOLIFIELD. Thank you very much.

Dr. WARREN. Then if I could go back to my own statement.

Representative HOLIFIELD. Certainly he puts the issue very plain in his presentation there.

Dr. WARREN. Yes. He does this on a background of more than 30 years' experience in this field working with leukemia.

Representative COLE. Mr. Chairman, I would like to inquire of Dr. Warren if he could interpret Dr. Furth's comment with respect to the need for long-term research in which Dr. Furth says it is a disappointing struggle to undertake such research. What did he have in mind?

Dr. WARREN. What he has in mind is this: It is much easier to obtain support and much more satisfying for the scientist to work in a field where he can hope to get results in 1, 2, or 3 years, rather than to work with long-term experiments where he may spend his whole life and still come up with an unsatisfactory result at the end of that period of life. This is the sort of thing that makes it so essential to continue on a long-term basis our studies of the population in Hiroshima and Nagasaki. We may get very few results.

I would like to point out that the results at the lower end of the scale that have been used by Dr. Lewis are not considered as actually statistically significant. They may provide a guide, but I would not want to base any firm conclusions on them.

These studies must be continued. But we know that the chances of getting significant results are relatively few. This is a discouraging type of work. It is hard to get support for it because we have to be honest and say it is quite possible that we will spend funds for 20 years and then not have anything to show you. It was that that Dr. Furth was commenting on.

Representative COLE. Thank you.

STATEMENT OF DR. SHIELDS WARREN—Resumed

Dr. WARREN. I would like to make it clear that much has been learned about radiation effects. Now I am speaking for myself. There is much more still to be learned. We have a great deal of data from animal experimentation. We have in addition much data on the effect of radiation on man derived from a number of different sources. These are perhaps worth mentioning.

You have heard of the normal or background radiation to which all of us are subjected. We know that the human race not only has developed in background levels of radiation similar to those of Washington but in regions such as Denver where the radiation is greater. Thus, during 30 years in Washington, a person might receive on the average a total accumulated dose of about 3.1 roentgens. In Denver or other mountain regions, because of increased cosmic radiation, this background might go as high as 5.5 roentgens.

In India a large population has lived for many centuries in the state of Kerala on sandbanks containing monazite. Recent studies of the radiation in this area have shown it to be up to 5 or even 50 times normal background. This population will be studied very carefully medically, but it is of interest that this relatively high level of radiation has not been sufficiently obviously detrimental to the population as a whole to cause abandonment of the region. However, one cannot say what the effects have been until very careful studies have been carried out.

The misfortune of men and women in the past has been wisely utilized by scientists to gain information as to the acute and chronic effects of radiation, and we actually have, as you have heard from the

experts testifying today, a large body of information as to what occurs in man.

To review briefly, we have data on acute exposures at varying levels of radiation from Hiroshima and Nagasaki. The studies on the degree of shielding from radiation afforded by structures in which the survivors were at the time of explosion are now being carried out and will greatly sharpen the information that we now have.

We have data on acute radiation exposure from those involved in the Los Alamos accidents and the minor accident at the Argonne. Some acute radiation from the shorter lived radioactive components of fallout of the close-in type was received by the crew of the Japanese fishing vessel and the Marshallese Islanders in 1954.

Data on chronic radiation in humans derives from the early workers with X-rays and radium as well as from radiologists up to the present day. Also, a considerable body of information has been gathered from patients treated for one or another disease with radioactive isotopes, radium or X-rays.

In general, we know that exposure to acute whole body external radiation will produce death for 50 percent of those receiving about 400 to 600 r.

Second, a single dose of radiation produces life shortening at significant levels. Human beings are too variable in their responses to radiation and in their state of health to permit any direct correlation, but it is probable that an acute dose of about 300 r. or repeated small doses totaling 2 to 3 times that would produce up to 5 years' shortening of life span. It will produce an increased incidence of leukemia. At present the rate of leukemia for the few most heavily exposed survivors at Hiroshima is about 1.3 percent. Radiologists, some of whom have received chronic irradiation on the order of 1,000 r. have 7 to 10 times as much leukemia as has the general population.

If there is a large neutron component in the initial acute exposure to radiation the likelihood of development of cataract is increased.

Radiation, whether acute or chronic, has a definitely damaging hereditary effect, because, in contrast to most cells of our bodies, there is no threshold for damage to the hereditary material and there is no recovery from injury in them. In chronic radiation, this is an important difference between the effects on most cells of a person's body and the effects on his germ cells. Since there is an appreciable power of repair possible in the body cells a higher dose is required to damage them seriously than is required to damage the hereditary material that perpetuates the race.

With acute or chronic radiation there is what is called a threshold effect in body cells. In other words, because many cells can continue to function even though irradiated and many cells in the body can be repaired even though damaged, we find that at low levels of radiation there is no observable effect.

This morning you heard mention of Senator Anderson's wristwatch. My own wristwatch has a luminous dial, and I measured the radiation from this on the back of the watch, putting the measuring device in the position of the skin on the back of my wrist. Assuming that I wore this 12 hours every day—actually I wear it a little more—the skin on the back of my wrist would receive 10 milli-r, or ten-thousandths of an r, and has been receiving it for close to 20 years. Yet this skin is just as normal as is the adjoining skin. That is, I feel

there is a definite threshold effect, and that until this threshold effect is exceeded, I am not going to stop a radioactive wristwatch.

This power of the body to repair itself, other than the hereditary material, has important bearing on the amount of radiation that man can withstand without demonstrable evidence of harm.

The present rate of testing of atomic weapons is such that the radiation from worldwide fallout is appreciably less than the background radiation. From the standpoint of heredity we should watch closely the levels of radiation.

The National Academy of Sciences report on radiation indicates that the doubling dose for mutations probably is in the range of 30 to 80 r, but may be as low as 10 r; it has been suggested that it could possibly go even as low as 5. Many geneticists believe that 30 to 50 r may be the doubling dose.

Representative COLE. Would you explain what you mean by a dou bling dose for mutations?

Dr. WARREN. Yes. There are a certain number of mutations that occur in the race quite naturally at the present time. You have heard of infants that have been born with imperfectly formed digestive tracts, for example. You have seen people who have 1 blue eye and 1 brown eye. These are the extremes of the sorts of mutations, some insignificant and some significant. We have hundreds of thousands of genes, and a change, a mutation in any one of these will produce changes under appropriate circumstances in the cells that are derived wholly or in part from that.

Senator JACKSON. Mr. Chairman—at that point, how can you tell whether it is due to the inevitable process of genetics and how can you tell when it is due to outside influence? How can you trace it?

Dr. WARREN. Only by very careful experimentation. These estimates are based on the best experimental data that we have available at the present time. There is some evidence derived from the eighty-thousand-odd births that have been studied in Hiroshima and Nagasaki as well.

So I would rather not answer that question in detail, because there are others who are geneticists who will be speaking. But in general I feel that we have reasonably sound foundations to emphasize that probably 30 to 80 r is a pretty good estimate for a level of radiation that will bring about twice as many mutations as now occur in the population.

Senator JACKSON. But all mutations are not due to radiation.

Dr. WARREN. No, indeed; not all congenital effects are due to mutations. For example, mutations can be simulated very closely by injury done to a fetus in utero, if the mother has had an attack of German measles or certain of the other types of virus diseases.

Senator JACKSON. While you do not want to go into this, I take it, because this is more a problem for the geneticists, you feel that they can tag and differentiate between mutations that are a natural result—the inevitable mathematical conclusion out of so many births—and mutations due to the outside influence of radiation?

Dr. WARREN. Yes. There is a very large-scale experiment that Dr. Russell, who is carrying on that experiment at Oak Ridge, will go into for you in the course of these hearings.

Senator JACKSON. I think it would be very important because this goes to the heart of the problem and unless you can tag them and

associate them with the problem that we are reviewing here, it would not be meaningful.

Dr. WARREN. Yes. Although not a geneticist, but as a scientist I am firmly convinced that radiation will produce mutations. The estimates that have been made by the majority of geneticists appeal to me as reasonable and sound estimates.

Senator JACKSON. In that connection, Dr. Warren, have there been and studies made of the situation as in Denver where people live at 5,000 feet as distinguished from people living at sea level? I was told that these mutations do not occur as anticipated.

Dr. WARREN. One would have to get a much higher level than occurs in Denver to reach the doubling dose that we have spoken of.

Senator JACKSON. What about in the Andes?

Dr. WARREN. The difficulty in the Andes—I have been at Moracoacha and a number of the other high altitude villages in the Andes—is that the population there is so short lived from other causes—public health is so poor—that it is very difficult to get any satisfactory statistics. I think that we can hope to get much more valuable data from the studies in the monazite areas and these studies are being carried forward by the Indian Government at the present time.

Representative HOLIFIELD. Of course, the length of life in India is much shorter than it is here.

Dr. WARREN. That is quite true.

Representative HOLIFIELD. There are a lot of factors that might enter into it, and not only the comparison of their longevity and ours, but also there would have to be a comparison of the average length of life in India, and those who live on these monazite sands.

Dr. WARREN. Very fortunately there is a very similar population of the same ethnic character and the same social status who live about 10 to 20 miles away. There has been no significant intermarriage between the two groups. So we hope that the Indian Government will have a good built-in control.

I have been speaking of this possible level of the doubling dose of 30 to 50 r. Since there is uncertainty in these figures and since many years of observations will have to be made before they can be firmed up we should take no chances but use a conservative figure such as 10 r for all types of added radiation, of which medical diagnostic X-rays will use a portion.

Representative HOLIFIELD. At this time, in order to get a realization of what a chest X-ray would expose a person to, how many roentgens would you say a person would receive from a chest lung X-ray?

Dr. WARREN. This would depend on the type of X-ray, Mr. Holifield. If it were one of the photoroentgen type, it would be higher than a full chest. We are speaking here not of the direct X-ray, but the scatter from that direct X-ray to the gonads. You heard this morning from a very competent radiologist, Dr. Friedell, and since he is still in the room, I believe, I wonder if he could tell you what he uses. That would make the point even stronger and more real.

Representative HOLIFIELD. Dr. Friedell, I suggest that you come forward. You do not need to leave your chair, sir.

My question, to make it more direct, would be this: What would be the exposure of a chest X-ray—as long as you are here, I will add another—and a fluoroscoping examination of the chest, and what would be the scatter to the gonads?

Dr. FRIEDELL. I am glad you make this distinction. First of all, there is a difference between radiation on the thorax and radiation to the gonads. The radiation to the thorax is considerably larger than to the gonads. As Dr. Warren pointed out, that makes a difference whether you have the miniature kind of chest examination which is really a photograph of a fluoroscopic image or whether you have an ordinary X-ray film that many of you have had for various studies.

Somewhere of the order of six hundredths to one tenth of a roentgen is given to the thorax for an exposure to get a satisfactory chest film. Depending on the various methods that are used for protection of the gonads and the possible protective devices which may be placed over the gonads, the dose to the gonads is considerably reduced. From the scatter alone, it may be as low as one one-hundredth of the dose given to the thorax. I would not want to put a firm figure on it because it is a function of how it is done.

From the point of view of fluoroscopy, there is not any comparison between the amount of radiation delivered to the chest and to the gonads, because of scatter when fluoroscopy is used, because at the present time the fluoroscopic methods require a large dose of radiation to be visible on the fluoroscopic screen. Depending on the time, I would say that a chest could easily receive as much as 5 to 15 roentgens in one examination.

Representative HOLIFIELD. In the case of exploring for a swallowed safety pin by a child, for instance, where you have to probe with instruments, and you follow it with your fluoroscope, what would be the exposure?

Dr. FRIEDELL. That is difficult to estimate, but I think this would help you. Most fluoroscopic machines will turn out somewhere in the order of 5 to 10 roentgens a minute. Some will turn out much more, but they are not really carefully controlled. Generally the lower limit is about 5 roentgens a minute. This determines in effect how much radiation will be received by the body in general, and is generally fairly easy to calculate what might be received by the gonads. If the radiation is directed to the gonads for various reasons, they receive much more.

Representative HOLIFIELD. Do you think there is a comprehension on the part of most radiologists of the importance of the damaging effects of this scatter from a genetics standpoint?

Dr. FRIEDELL. I think this is a difficult question for me to answer. I know that people in whose circle I move are very concerned with the problem and are examining it very carefully. I would say that the radiologists in general are now very acutely aware of this problem. It is conceivable that they were not aware of it 10 or 15 years ago, and are now beginning to institute all the necessary measures to get as much protection as we can.

Representative HOLIFIELD. Certainly when they are utilizing a machine with such potentially damaging effects, they should from a professional standpoint guard the people as much as possible.

Dr. FRIEDELL. I think I would agree with this, but I would also like to add to this that you are always faced with the problem of measuring the value of this medically as compared with the possible hazard that is introduced. This is a very difficult thing to measure sometimes. It is conceivable that much error can be introduced, but

I think that most physicians are acutely aware of weighing these two things and must do the best for the patient.

Senator HICKENLOOPER. I would like to ask Dr. Friedell or Dr. Warren a question or two.

I wonder if you ever knew Dr. Erskine?

Dr. FRIEDELL. Yes, in Iowa.

Senator HICKENLOOPER. He was an old friend of mine who died a few years ago. He died without doubt from radiation which he got in the early days from his experimental work. He did some pioneering work, especially on the mechanics of measurement of radiation in those days.

The question I want to ask is somewhat along the line of Congressman Holifield's question. From a statistical standpoint, I think manifestly years ago—20, 30, 40 years ago—when the average small or large town physician's office did not seem complete unless he bought an X-ray machine, and without doubt used it with great frequency without realizing the potentials of this machine, without the ability to measure quantities or absorption or anything of that kind, and with little or no schooling in it, I wonder if there is any statistical background that would tell us how many cases of leukemia or perhaps induced cancer or something of that kind might have occurred in the American population during those periods when there was very little appreciated as to the long range possible effects of radiation of this kind.

Dr. WARREN. I think I might be able to answer, if I might, Senator Hickenlooper.

Senator HICKENLOOPER. Yes.

Dr. WARREN. I had been interested in the problem of the life span of both radiologists, general practitioners and certain specialists. We find that the life span of the general practitioner is not significantly at variance with the life span of white males over 25 in the United States. The average doctor starts his practice somewhat around 25 years of age, so that is what we took.

This means, then, that the average doctor, not a specialist in radiation or not in the specialties using radiation a great deal, such as orthopedic surgery, urology and some of the other specialties, has about the same life span. There is evidence that he has slightly more leukemia, but not as much as the radiologist who has 7 to 10 times as much as the males in the general population. He has possibly half again as much. It is rather hard to pin it down exactly.

I think it should be remembered that there are relatively few of the general practitioners who used their X-ray machines all day long. They would use them from time to time on their patients, and had appreciable rest periods during which their body cells could recover from the radiation injury done.

Senator HICKENLOOPER. I either heard or read some testimony with respect to the data on physicians, but the real point of my question I was directing at the use of X-ray in treatment years ago on patients when the effects of those X-rays were not so well known, and there was a period of time some years ago when it was really quite widespread, and there is no telling what the strength of the treatment would be that many patients received at that time. I wonder if there would be any statistical data that could indicate malignancies of various types from that treatment, rather than from natural causes.

Dr. WARREN. You saw on the chart an estimate as to X-rayed adults here. I think that the best data on this are the group with so-called ankylosis spondylitis—a form of arthritis of the spine—an X-ray treatment gives some relief to the pain and may help the course of the disease somewhat. A group under the direction of Dr. Court Brown in England studied this very carefully. I have here the white paper on radiation effects issued by the United Kingdom approximately a year ago. It gives an indication that the dose ranges ran from as little as 500 *r*, or possibly a little under that to the spine, up to more than 2,750 *r*; that this caused an increase in the crude incidence of leukemia—these are uncorrected figures—ranging from 4.1 per 10,000 people treated at the lower dose level, or 2.2—which might be sheer chance, at less than 500 *r*—up to 17.6. So arguing from this, I think it might be said that there were probably a scattering of cases of leukemia induced in the way you spoke of.

Senator HICKENLOOPER. Would you have an estimate at this time as to how long a period of time it has been since you feel that you can have some reliable data on leukemia, and many other ailments which people undoubtedly had many years ago, but which were not diagnosed by the physicians? I remember when they used to say people died of acute inflammation of the bowels, when it was probably a burst appendix, and that sort of thing.

Dr. WARREN. Yes. I think you pointed out a very important thing, Senator Hickenlooper, that medical diagnosis is steadily improving. I think in certain areas of the country in the larger medical centers, leukemia has been pretty well recognized from 1930 on; for the bulk of the country, leukemia has been very well recognized from 1945 on. I think our statistics from 1900 to 1910 may have caught perhaps half of the leukemia cases or something of that order. This is only a wild estimate, however.

Senator HICKENLOOPER. Thank you very much.

Representative HOLIFIELD. Thank you very much. You may proceed with your statement.

Dr. WARREN. At present the rate of radiation from fallout gives a probable 30-year dose of 0.1 roentgen. The data on chronic radiation to our bodies and those of animals indicates that rather more than the acute lethal dose of radiation can be withstood, though not without harm, if it is given over a protracted period of time. The effect of protracted radiation may be half or less as great as radiation given at a single time. If significant damage is done to body cells there is never complete repair, but rather atrophy persists and eventually cancer may develop.

The ill effects known to come from chronic radiation, are, as you have heard, damage to various body tissues ranging from the destruction of cells to undue or cancerous proliferation of cells. Thus, in the skin of the early radiologists, we saw atrophy occur, finally ulceration, and in some instances even skin cancer. The blood responds at first to radiation at low levels by minute and insignificant changes in some cells. For example, the lymphocytes may show a rare cell with double nuclei, the meaning of which has not yet been established. Continued exposure to radiation leads in some people to the failure of formation of adequate blood cells condition known as anemia or agranulocytosis, or, at times, to an overly enthusiastic reparative response which leads to the development of leukemia. Chronic exposure

from radium, particularly radium absorbed internally, has been shown to be injurious and radiation changes in bone can be detected with levels of radium in bone as determined years afterwards on the order of 1 microgram. Of course, these levels were initially appreciably higher.

Since one of the radioactive fission products, strontium 90, is deposited in bone, there is much concern to advance our knowledge of radioactive strontium, the amount that enters our bones, and the effect that it may have there. Strontium 90, at fallout levels or at levels many times higher, has no significant genetic effect. Neither is there firm evidence that it has a leukemia producing effect. If we assume that the radiation effect from strontium 90 or from other sources has no threshold (and this assumption is contrary to most existing information with regard to somatic effect) if we assume this, I say, it would follow that there would be a small statistical increase in bone tumors. I doubt very much that it would cause any increase in leukemia. It is striking that in those persons who have had radium deposited in their bones there has been no evidence of leukemia, even though they have developed bone sarcoma. The evidence for the possible development of leukemia from strontium 90 rests on mice treated with radioactive strontium that showed leukemia. However, leukemia is so common a disease spontaneously in mice that I hesitate to accept this observation as contradicting the information we have from experience with humans and with a number of animal experiments at the present time.

Let us, however, make the worst assumption, that there is no threshold and that we might be concerned with a linear increase in both leukemia and bone sarcoma. On this basis, as you have heard, the average level to be expected from uptake of strontium 90 already produced by weapons testing may be about five so-called sunshine units. While there is no evidence that even 10 times this level is harmful, if we assume that there is no threshold, I would be reluctant to see the average strontium 90 content of bones, particularly in children, go much above 10 times the present level. It is possible that additional experimental work will enable us to go safely beyond this tenfold increase.

Representative HOLIFIELD. Thank you very much, Dr. Warren.

Senator Jackson, do you have any questions?

Senator JACKSON. I have no further questions. I am very happy to see Dr. Warren back with us. We are very proud of his great contribution while he served as Director of the Division of Biology and Medicine of the Atomic Energy Commission.

Dr. WARREN. Thank you very much, Senator Jackson.

Representative HOLIFIELD. Dr. Warren, will you be back with us in a few minutes for our discussion period?

Dr. WARREN. Thank you.

Representative HOLIFIELD. At this point I would like to say that it is my understanding that Dr. L. H. Hempelmann, of the University of Rochester, Strong Memorial Hospital, will deliver a paper in Pittsburgh on June 11, called Irradiation-Induced Cancer in Man. When we receive a copy of this paper I would like to insert it into the record at this point.